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METHODS OF SHUTTING OFF WATER IN OIL AND GAS WELLS

BY

F. B. TOUGH



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METHODS OF SHUTTING OFF WATER IN OIL AND GAS WELLS.

By F. B. TOUGH.

INTRODUCTION.

This bulletin deals with a topic that is exceedingly wide, and will doubtless be under consideration and discussion so long as there are enough known deposits of oil and gas remaining in the earth to make their revelopment profitable. The Bureau of Mines has repeatedly called attention to the importance of protecting oil or gas sands from the encroachment of water, and the purpose of this paper is to summarize existing knowledge of methods and devices.

Water may gain access to an oil-bearing formation from several sources—from water sands above or below those containing the oil, or by encroaching through the oil sands as the oil is withdrawn. In short, it may enter a well from the “top, bottom, or side.” Such ingress of water is a most serious detriment to the recovery of oil from the ground.

As the art of drilling and developing oil properties has progressed, increasing thought, labor, and money have been expended on various methods, devices, and equipment for arresting the migration of water from its normal subsurface position into the porous strata containing valuable oil or gas accumulations.

At an early stage in the oil-field development of California it became evident that considerable modification of accepted drilling practices was necessary in order to meet the conditions imposed by the poorly consolidated shale, clay, sand, and boulder beds penetrated, as well as the hard layers of sandstone and calcareous shale, which vary greatly in thickness, hardness, and frequency. These hard streaks are commonly called “shell,” and are so reported in the well logs. As deeper and deeper territory was prospected, drillers from the older fields of the East, as well as from Texas and Louisiana fields, took part in the operations. The practice evolved was thus based on the wide experience of a most cosmopolitan group of men who, considered as a group, were not hampered by being limited to the knowledge of the practice at any one locality.

The first part of this paper deals with the California methods of shutting off water in oil and gas wells. Subsequent chapters are devoted to a brief description of some methods used in the Mid-Continent and the Gulf fields for shutting off water, and contain some suggestions for modifying California methods to make them applicable in these localities. No effort is made to cover in detail all of the Mid-Continent or Gulf methods for handling water troubles.

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DEFINITIONS OF TERMS.

Various patents have been issued by the United States Patent Office that cover partly or entirely a particular process or method of shutting off water. In this report names, such as "Grahm float plug," "Perkins process," and "Baker sure-shot plug," are employed in the same sense as applied in field operations where the process or appli-

ance was observed. Such names are used with quotation marks to indicate that no responsibility for their legal correctness is assumed. Frequently two men working in different fields will solve a similar problem in practically the same way, and each without any knowledge of the other's work. Thus it is no reflection on any man's work if a certain operation be described as having been conducted by some one else.

The word "cement" refers to a good grade of Portland cement. Several manufacturers are now marketing a cement especially proportioned and ground for use in oil wells. Of course any of the various methods of cementing can be used with any suitable cementing material.

The term "shell" is used to denote layers of hard sandstone or hard calcareous shale penetrated by the drill.

The term "blowing" a well refers to the practice of permitting the gas to blow unrestrained in order to free the well of accumulated water, or for any other purpose.

"Mud flush" is the muddy water used for the purpose of flushing drill cuttings out of the hole, as distinguished from "mud fluid," applied for sealing off porous strata. A full discussion of what constitutes mud fluid in well-drilling operations is given on page 59.

The term "mudding" refers to the application of mud fluid to a well. A well to which the mud-fluid method has been applied is said to be "mudded."

The term "water shut-off" refers to shutting off a water-bearing sand in the well by any of the methods used.

A "formation" shut-off is had when the hole is so cased that the casing makes a tight fit with the walls of the hole, without the use of cementing material or packers.

A "formation" packer is a packer of rubber, burlap, or other material which presses against a formation penetrated and makes a tight fit between the casing and the walls of the hole.

HARMFUL EFFECT OF WATER ON PRODUCTION OF OIL AND GAS.

As the present paper deals exclusively with ways and means for excluding water from an oil well or a gas well or from strata containing oil or gas, consideration may first be given to the damage occasioned when water is admitted by improper drilling. A few observed facts, rather generally recognized in the production of petroleum, have a direct bearing on the subject. These are stated briefly in the following discussion:

When a new well is being drilled in virgin or slightly depleted territory, little water will "run away" or enter the oil-bearing sands, and the small volume so entering is readily ejected by the gas and

is pumped out. The greater the degree of depletion of the oil contained in the sand in the vicinity of a well, the more readily will the sand take water, and, likewise, the more difficult is the removal process. An important factor is the greater surface tension of water as compared with that of oil. Another important factor is the decrease in the expulsive force coincident with the exhaustion of the gas. Water once admitted to the depleted sand hangs tenaciously in the interstices, thus retarding the flow of oil to the well. A new well in a partly depleted field or sand may suffer in this respect just as an old well being redrilled.

It is well recognized in California, Mid-Continent, and Gulf coast fields, and probably elsewhere, that such ingress of water is usually attended by a great decrease in the volume of oil produced by the well or wells affected. In addition to the causes just stated, the chilling effect of the water on oils of paraffin base may cause the formation of wax in the sand adjacent to the well and further retard production.

Many operators in eastern fields contend that a small volume of salt water, which is usually of a higher temperature than fresh water, has a beneficial effect on production, as its heat tends to offset the refrigerating effect of the expanding gases as they enter the well. If any such beneficial effect can justly be attributed to the action of salt water, the effect will probably be limited to sands in which the water is present with the oil. The effect of such water is very different from that of water let into a well from an unproductive sand. Although the writer has no data to demonstrate that the salt water can not have the beneficial effect mentioned, he is of the opinion that the theory has been too widely applied as a justification for the presence of water admitted to productive sands by inefficient or careless drilling operations.

Even if it can be proved that as regards a particular drilling operation the entrance of a small volume of salt water has actually increased the daily production of oil, the condition is not justified until the operator can also demonstrate that the increase in production more than compensates for the cost of pumping the water and of replacing corroded tubing, casing, pumps, and other piping and fittings. Also the operator should be prepared to offer some conjecture as to whether the increase in daily production represents a greater ultimate extraction of oil from the property. It might happen that a temporary stimulation of production would not increase the total recovery of oil.

DATA ON CALIFORNIA WELLS.

The detrimental effect of water on some California wells is clearly shown in the following extract from Bulletin 73 of the California State Mining Bureau:*

The diagram here presented (fig. 1) is almost self-explanatory and shows that well 1-C was the first in the group to produce water, which quickly increased in amount accompanied by an equally rapid decrease in the amount of oil. It will be noted that the other wells in the group later followed a similar course. This indicates that well 1-C is the source of the water trouble.

It is instructive to note that the water admitted through well 1-C flooded the oil sands and largely cut off the production of the other

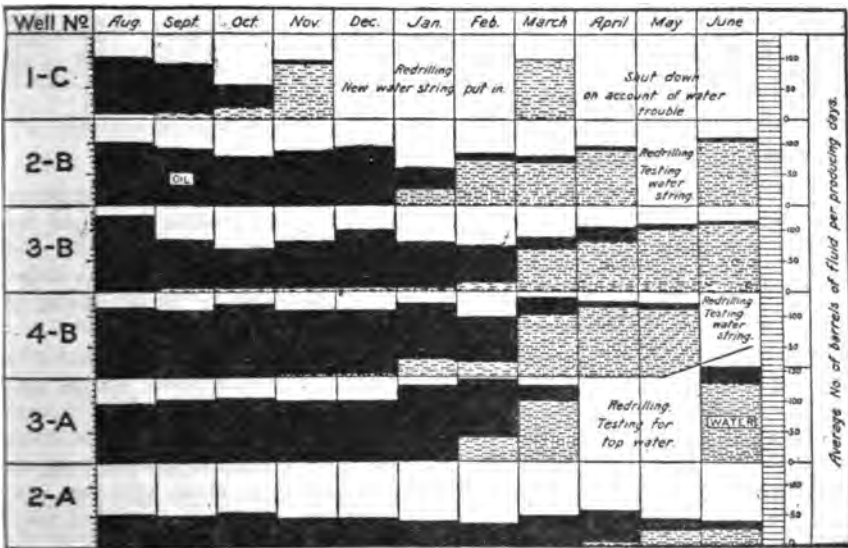


FIGURE 1.—Diagram showing volume of oil and water produced by certain wells.

wells of the group as shown in the diagram. Another instance, from the Kern River district of the California fields, also reported by the California State Mining Bureau, will suffice for the present purpose.

An investigation was made by the State Mining Bureau engineers, which resulted in recommendations for repair. In order to expedite matters, it became necessary for the State officials to assume full charge of the well, and, with the consent of the owner, place a specially selected crew of workmen on the job. The crew was furnished by the Santa Fe Co., and did excellent work.

* First annual report of the State oil and gas supervisor of California, fiscal year 1915-16, State Mining Bureau, 1917, p. 114.

The daily production of oil and water from affected wells, before and after repairs, is shown in the following table:

Data showing results of efforts to exclude water from certain oil wells in California.

Well.	Production before repairs.		Production after repairs.	
	Oil.	Water.	Oil.	Water.
	Barrels.	Barrels.	Barrels.	Barrels.
Alma Jr. No. 1.....	Trace.	150	7	0
Alma Jr. No. 2.....	0	12,000	Trace.	100
Alma Jr. No. 5.....	Trace.	200	10	Trace.
Alma Jr. No. 11.....	Trace.	250	1	40
Alma Jr. No. 12.....	Trace.	200	10	25
Santa Fe No. 1.....	3	32	4	10
Santa Fe No. 2.....	0	1,440	(a)	(a)
Santa Fe No. 6.....	5	250	4	20
Santa Fe No. 10.....	5	400	5	10
Santa Fe No. 14.....	5	5	5	10
Santa Fe No. 18.....	7	1,000	7	25
Total.....	25	15,927	59	240

a Not yet rigged for pumping.

It is worthy of special note that no new mechanical methods were necessary to successfully plug the well. The success of the undertaking is due to the fact that a thorough investigation of conditions was made in a scientific and methodical manner by the trained men of the State Mining Bureau, who determined which well of the group was admitting the water to the oil sands, as well as the most efficient means for excluding it. * * *

The repair work cost in the neighborhood of \$10,000, required about five months time, and resulted in the elimination of two compressor plants, previously employed in lifting about 15,000 barrels of water daily, which is now excluded from the wells. Elimination of the two compressor plants saves nearly 100 barrels of fuel oil daily, and stops other operating expense amounting to about \$500 per month. This saving amounts to about \$115 per day. Besides these economies, the production of oil from affected wells has been slightly increased, making the total daily saving about \$150, which is a yearly profit of over 500 per cent on the expenditure for repairs.

EXAMPLES FROM OKLAHOMA FIELDS.

A similar instance from the Cushing pool in Oklahoma may be of interest. Offsetting wells along the common property line of two adjacent properties were making great volumes of water and small volumes of oil. One of the companies, on the recommendation of the Bureau of Mines, cemented the bottoms of five of its wells. This work resulted in more than doubling the total oil production and in reducing the water to approximately one-quarter of its former volume. The other operator refused to consider similar work in his wells and when last interviewed was still pumping oil and water in unchanged volumes.

The superintendent of an Oklahoma property stated that he mixed a batch of cement and poured it into a well having about 1,800 feet of water in it. Finding that the cement did not set, he con-

cluded that it would not set under a head of water. Had the cement set after having been poured through such a column of water it would have been a most remarkable cement. Cement may be carried into a sand by a rapidly moving current of water where it is quickly filtered out as later described under the "McDonald method" of cementing, but to pour cement either dry or neat through a static column of water, thus permitting it to settle gradually to the bottom of the well, a process that may require several hours or days, is not to be considered.

Some oil men contend that cement will not set under water, particularly salt water. The general use of cement in California and Louisiana under both fresh and salt water has absolutely demonstrated that such an opinion is untenable. The thousands of cubic yards of concrete in breakwaters and other marine construction might also be cited.

The detrimental effect of water on gas production is too well recognized to require more than passing mention. It is common practice to blow a gas well periodically in order to remove accumulated water. If a well is allowed to fill too far with water, the flow of gas will decrease and may entirely cease. Many good gas wells have been entirely and permanently killed by allowing water to stand on the productive sands for a considerable length of time. This effect is due partly to the ready compressibility of gas, and partly to the fact that gas has no capillary force with which to oppose the ingress of water.

MEANS FOR PREVENTING WATER TROUBLES.

A most important phase of shutting off water can only be indicated here. It involves ways and means for studying conditions in a field to enable the adoption of the best and most economical methods for handling water and production problems in new wells, and for repairing damage caused by improper drilling, or failures in materials of older wells.

An accurate and comprehensive series of records covering operations and their results constitute the foundation for such work. Mere logs of wells, no matter how complete, do not suffice. Records for each well should be kept showing the rates of production, and the percentage of impurities, such as water, emulsion, sand, and mud. Such gages should be taken at regular and not too infrequent intervals, and the results should be recorded on a special form prepared with due regard for convenience in filing. Such production records are in addition to those of lease production, pipe-line runs, and storage.

Dealing with the water problem in oil fields may be considered in two separate phases, as follows: Drilling precautions to prevent the incursion of water into pay strata; remedying such intrusion

after it has commenced. If any assurance was to be had of the universal success of drilling precautions there would be little or no need for keeping the records mentioned. Costly experience has demonstrated that no such success can rationally be expected. The keeping of such records is much like fire insurance. If there are no fires, the insurance is unnecessary, but if fires do occur, the insurance is most desirable.

Similarly, when the presence of water is observed in a field or a part of a field, it is of small value to hurry around taking cuts every day on the production from each of the wells within the affected area. If cuts taken at regular intervals are available, synchronous curves may be plotted, showing the increase in water and the decrease in oil produced by each well of the group. These will show in which well, or group of wells, the water first appeared, and will assist in tracing its course. Moreover, if careful note has been made of the natural water levels and other characteristics of waters penetrated in drilling, such as sulphur content, salt content, or whether fresh or alkaline, and the temperature, etc., it may be possible to determine, or, at least, form a reasonably well-grounded opinion as to whether the water is from above or below the productive sands.

A certain company takes samples of all water encountered if a representative sample can be obtained. The samples are appropriately marked and are stored in half-gallon corked bottles. Most of such samples are never used, but occasions have arisen where information based on a comparison of the chemical analyses of two such samples was worth to the company many times the cost of collecting the samples and making the analyses.

It is most important to realize that the collecting and recording of such data is really inexpensive and can usually be effected without putting on extra employees to handle the work. If some one arranges a convenient set of forms for the use of the foreman, or whoever is best situated for doing the work, and supplies the necessary apparatus for making the tests, the most difficult step has been taken. After the new duties have been explained and assigned to an employee, his hearty cooperation can nearly always be relied upon.

Such records should be in duplicate, at least, and filed in widely separated places, such as field and city offices, as a protection against total loss by fire.

An excellent discussion of this subject with reproductions of forms in use will be found in Bulletin 73 of the California State Mining Bureau.*

*First annual report of the State oil and gas supervisor of California, fiscal year 1915-16, State Mining Bureau, 1917, pp. 110-116.

When water troubles have been narrowed down to one or a few wells, bridging, packer, or other tests may become necessary to definitely determine the source of the water, and to indicate the proper means for excluding it.

The rubber wall packer is considered a suitable testing device, though packers may also be used with hemp or other fiber as a packing material, either woven or loose, when set inside a string of casing. A good example of this usage is the operation of the "Crumpton packer," as described in subsequent pages.

Various kinds of "formation" packers (rubber, lead, or other material used to make a tight fit between the casing and the wall of the hole) are used in the Mid-Continent and Eastern fields for shutting off water. Generally the packing material is rubber. It is well known that rubber is soluble in petroleum and many of its fractions, and will harden under water or in the air, thus losing the elastic property that makes it valuable as a packer. Therefore its use as a permanent packing material for oil or gas wells can not be considered. Experience has shown that gas wells frequently will blow out large chunks of the rubber packers set in them to shut off water. The only safe use of the formation packer in oil and gas wells, for any more than a temporary shut-off, is when a large quantity of hemp or fiber is used, and in addition mud fluid is circulated and allowed to remain back of the casing and above the packer. Thus, if the packer ever fails, the mud will rush into the well, making the source of the trouble evident, requiring immediate repair or plugging. Even this use is permissible only where no other means are available to accomplish the desired end.

PROBLEMS INVOLVED IN EXCLUDING WATER.

In making an intelligent effort to keep water out of a barn or a house or an oil or gas well one must first discover as best he can where the water is getting in. As regards a well, all possible sources must usually be considered and checked off by elimination until the problem is solved. In the California fields, besides top and bottom waters, there are large and important areas where one or more water-bearing sands are encountered between productive beds. In some localities there are two of these intermediate water sands with valuable oil and gas bearing strata above and below each water sand. Each productive stratum is separated by 10 to 200 feet of shale from the nearest water sand above or below it. Obviously the water conditions of any one well in such territory might be the basis of a long treatise, and a method of shutting off water might be advisable under some conditions that would not be best suited for another well under somewhat different conditions. Again, it may be

come necessary to use a different method in shutting off intermediate water than has been used in shutting off top water in the same well. The physical conditions of the hole, such as friction on the working string of casing and the position of lost tools or pipe that may have been sidetracked or drilled past, the exact purpose of the job, and the apparatus available, all enter as factors in the selection of a method for shutting off water at a particular well.

For convenience all the chief methods of shutting off water are described here as they are used in shutting off top water before the oil sands have been tapped by the bit. A general discussion of variations in the methods when they are used for shutting off bottom or intermediate waters is also presented.

DETERMINATION OF PROPER SIZE AND WEIGHT OF CASING FOR WATER STRINGS.

Stated in its simplest form, the problem of shutting off top water is to make a water-tight joint between a string of casing and the wall of the hole at some impervious stratum above the productive sands and below the water horizons. Another and equally important consideration that is sometimes overlooked is the necessity of using casing of such weight that it will not collapse when the hole is bailed dry. Every water string should be so designed that it will stand the severe test of being bailed absolutely dry without danger of collapsing the casing, although, of course, it is not always practicable to apply the test. In an area of high gas pressure bailing all the fluid out of a water string will often cause a dangerous blow-out. A blow-out of this kind might easily cause the formation to cave around the bottom of the casing and spoil what would have been an effective and permanent water shut-off. Such local conditions, however, do not relieve the operator of the obligation of so designing his water string that it will not fail when production has decreased to the point where the well is tuber far below the bottom of the water string and all the fluid pumped from it. Every operator knows when he commences to drill that eventually the well will be pumped for every gallon of oil that will seep into it, and he should drill with this result in mind or not drill at all. That is, he should either put the hole down properly or else go out of business before he ruins his own and, what is more regrettable, his neighbor's property also.

The most ardent optimist of the oil business—and if it were not for the optimist it is doubtful whether there would be any oil business—knows that the resistance of a water string to collapsing pressure decreases with age and usage. If the string of casing when new be not properly designed as to size and weight to withstand the

maximum pressure to which it will ultimately be subjected, what chance has it to do its work after it has been in the ground 5 or 10 years? These considerations bring out the important question, "What is the best method of computing the size and weight of casing to be used for a particular water string?" A prerequisite to such a computation is a fairly reliable estimate of the probable maximum pressure tending to collapse the casing.

To get such an estimate we may consider a well with the water string properly set in which the water rises to the ground surface on the outside, all the fluid having been removed from the interior of the pipe. These conditions give a minimum pressure at the bottom of the water string that is proportional to the depth at which the water is shut off, the pressure decreasing toward the surface, where it becomes zero. For convenience the maximum external pressure in pounds per square inch may be computed by multiplying the depth of the water shut-off in feet by the factor 0.434. Such a method does not consider the pressure that might be occasioned by sloughing of the side of the hole. However, the force of such a cave-in can not be computed on the basis of fluid pressure and is so variable that it can only be roughly estimated. If the external fluid is drilling mud with a specific gravity of about 1.10 as compared with water, the external pressure will be increased by 10 per cent. This difference is more than covered by the factor of safety, which likewise covers the fact that salty water shows a greater pressure than the factor 0.434 will give.

There are times in the life of a well when a shifting sand will shear off a string of casing or collapse it, or even two or three strings may be squeezed together until the sucker rods are held fast. Such conditions, as a rule, can not be foreseen and are most difficult to cope with. Sometimes previous experience in a certain locality with a particular formation may suggest extra precautions, so that the operator will use the heaviest pipe he can get for that part of the string exposed to the troublesome stratum. However, the suggested method of computing the external pressure on a water string has generally been found entirely satisfactory.

PRESSURES ALLOWABLE ON COMMERCIAL WELL CASINGS.

The next step in the design of a water string is to determine the pressures that may be safely carried on the various sizes of commercial well casings. The most authentic information at hand on this subject is that published by Stewart.* This paper formed the basis of a study by C. Naramore and R. S. Hazeltine, at Coalinga,

* Stewart, R. T., Collapsing pressures of Bessemer steel lap-welded tubes, 3 to 10 inches in diameter: Trans. Am. Soc. Mech. Eng., May, 1906, pp. 730-822.

Cal., in 1911. Later, Hazeltine presented a paper* on the results of Stewart's work as applied to the needs of the oil industry. Either of these papers will repay a thorough study by anyone facing water problems in drilling wells.

The following abstract from Stewart's paper is of especial interest:

This research was undertaken for the purpose of supplying an urgent demand for reliable information on the behavior of modern wrought tubes when subjected to fluid collapsing pressure. Every means known to engineering science that could aid in the accomplishment of this undertaking has been used, and every possible effort made to get at the truth and have the research yield trustworthy data. It was planned and executed under the immediate direction of the author, at the McKeesport works of the National Tube Co., and has occupied for its completion, during a period of four years, the time of one to six men.

Results of present research.—The principal conclusions to be drawn from the results of the present research may be briefly stated as follows:

1. The length of tube, between transverse joints tending to hold it to a circular form, has no practical influence upon the collapsing pressure of a commercial lap-welded steel tube so long as this length is not less than about six diameters of tube.

2. The formulas, as based upon the present research, for the collapsing pressures of modern lap-welded Bessemer steel tubes, are as follows:

$$P=1,000 \left(1-\sqrt{1-1,600 \frac{t^2}{d^3}}\right) \dots\dots\dots (A)$$

$$P=86,670 \frac{t}{d}-1,386 \dots\dots\dots (B)$$

Where P = collapsing pressure, pounds per square inch.

d = outside diameter of tube in inches.

t = thickness of wall in inches.

Formula A is for values of P less than 581 pounds, or for values of $\frac{t}{d}$ less than 0.023, while formula B is for values greater than these.

These formulas, while strictly correct for tubes that are 20 feet in length between transverse joints tending to hold them to a circular form, are, at the same time, substantially correct for all lengths greater than about six diameters. They have been tested for seven sizes, ranging from 3 to 10 inches outside diameter, in all obtainable commercial thicknesses of wall, and are known to be correct for this range.

By the foregoing formulas one may compute the probable collapsing pressure for any commercial size of casing.

Methods have been given for determining the probable pressure that will be carried on the water string of a particular well, and also the method for computing the collapsing pressure of the casing; it remains to discuss the proper safety factors to use. Quoting again from Stewart's report:

Not one of the several hundred tubes tested failed at a pressure lower than 42 per cent less than the probable collapsing pressure, while 0.5 per cent of the number of tubes failed at 37 per cent and 2 per cent at 25 per cent less than

* Hazeltine, R. S., Collapsing pressure of steel tubes: West. Engineering, vol. 1, July, 1912, pp. 295-297.

that pressure. In other words, with an actual factor of safety of 1.75, * * * not one of the tubes tested would have failed.

It would appear that:

1. For the most favorable practical conditions, namely, when the tube is subjected only to stress due to fluid pressure and only the most trivial loss could result from its failure, a factor of safety of 3 would appear sufficient.

2. When only a moderate amount of loss could result from failure, use a factor of 4.

3. When considerable damage to property and loss of life might result from a failure of the tube, then use a factor of safety of at least 6.

4. When the conditions of service are such as to cause the tube to become less capable of resisting collapsing pressure, such as the thinning of wall due to corrosion, the weakening of the material due to overheating, the creating of internal stress in the wall of the tube due to unequal heating, vibration, etc., the above factors of safety should be increased in proportion to the severity of these actions.

These recommendations by Stewart are absolutely sound engineering, and if a safety factor of 3 were used in oil-well work some costly redrilling jobs might be avoided. At the same time such a procedure would not only increase the cost of material, but would frequently necessitate decreasing the size of the next string of pipe to be inserted in the well, a serious disadvantage. The drilling proverb, "Keep the hole as big as you can as long as you can" is not to be lightly ignored.

Suppose, for example, it were necessary to shut off water in a well at a depth of 3,000 feet and a safety factor of 3 was to be used, Table 1 following shows that 6½-inch, 28-pound casing should fail with a water column of 9,380 feet. One-third of this, or 3,126 feet, would then be the permissible depth at which the casing could be used with a safety factor of 3. Similarly, 8½-inch, or larger, sizes would not meet the requirements with so large a safety factor. If no mistake occurs and the hole can be finished with one more string of pipe, nothing larger than 6½-inch open hole, or 4½-inch casing, can be used. In many localities a 4½-inch hole is undesirably small, and if any misfortune is met with, such as a failure to make a successful water shut-off with the 6½-inch string, either a costly redrilling job has to be done or the hole must be finished with a 3-inch liner into the oil sands or else the well must be abandoned.

TABLE 1.—*Collapsing pressures and capacities per linear foot of lapwelded steel casing of sizes commonly used in California.*

Size.	Weight per foot.	Outside diameter.	Inside diameter.	Thick- ness.	Collap- sing pressure per square inch.	Equi- valent water column.	Water column with safety factor of 2.	Capacity per linear foot.	Capacity per linear foot.
<i>Inches.</i>	<i>Pounds.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Pounds.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>U. S. gallons.*</i>	<i>Cubic feet.</i>
4 $\frac{1}{2}$	16	4.760	4.082	0.334	4,710	10,850	5,425	0.6792	0.0908
4 $\frac{3}{4}$	12.85	5.000	4.506	.247	2,900	6,680	3,340	.8281	.1107
4 $\frac{7}{8}$	15	5.000	4.424	.288	3,610	8,320	4,160	.7982	.1067
5 $\frac{1}{8}$	20	6.000	5.352	.324	3,290	7,580	3,790	1.1677	.1561
6 $\frac{1}{8}$	20	6.625	6.049	.288	2,380	5,480	2,740	1.4916	.1994
6 $\frac{3}{8}$	24	6.625	5.921	.352	3,220	7,420	3,710	1.4295	.1911
6 $\frac{1}{2}$	26	6.625	5.855	.385	3,850	8,410	4,205	1.3974	.1858
6 $\frac{7}{8}$	28	6.625	5.791	.417	4,070	9,380	4,690	1.3667	.1827
6 $\frac{3}{4}$	20	7.000	6.458	.272	1,980	4,560	2,280	1.6988	.2271
6 $\frac{1}{4}$	26	7.000	6.276	.362	3,100	7,140	3,570	1.6061	.2147
6 $\frac{1}{2}$	28	7.000	6.214	.393	3,480	8,020	4,010	1.5739	.2104
6 $\frac{3}{4}$	30	7.000	6.154	.423	3,850	8,870	4,435	1.5440	.2064
7 $\frac{1}{8}$	26	8.000	7.386	.307	1,940	4,470	2,235	2.2240	.2973
7 $\frac{3}{8}$	28	8.625	8.017	.304	1,670	3,850	1,925	2.6304	.3503
7 $\frac{1}{2}$	32	8.625	7.921	.352	2,150	4,950	2,475	2.5583	.3420
8 $\frac{1}{8}$	36	8.625	7.825	.400	2,630	6,060	3,030	2.4962	.3337
8 $\frac{3}{8}$	38	8.625	7.775	.425	2,890	6,640	3,320	2.4648	.3295
8 $\frac{1}{2}$	42	8.625	7.651	.487	3,510	8,090	4,045	2.3863	.3190
9 $\frac{1}{8}$	38	10.000	9.384	.308	1,280	2,950	1,475	3.5899	.4799
10 $\frac{1}{8}$	40	10.750	10.064	.348	1,420	3,270	1,635	4.1210	.5509
10	45	10.750	9.980	.365	1,800	4,150	2,075	4.0440	.5406
10 $\frac{3}{8}$	48	10.750	9.902	.424	2,030	4,680	2,340	3.9976	.5344
10 $\frac{1}{2}$	54	10.750	9.784	.483	2,510	5,780	2,890	3.9026	.5217
11	47	11.750	11.000	.375	1,380	3,180	1,590	4.9834	.6595
11 $\frac{1}{8}$	60	11.750	10.772	.489	2,220	5,120	2,560	4.7307	.6324
11 $\frac{3}{8}$	40	12.000	11.384	.308	840	1,940	970	5.2827	.7052
12 $\frac{1}{8}$	40	13.000	12.438	.281	800	1,150	575	6.3063	.8433
12 $\frac{3}{8}$	45	13.000	12.360	.320	750	1,730	865	6.2298	.8328
12 $\frac{1}{2}$	50	13.000	12.282	.359	1,010	2,330	1,165	6.1497	.8221
12 $\frac{3}{4}$	54	13.000	12.220	.390	1,210	2,790	1,395	6.0839	.8137
13 $\frac{1}{8}$	50	14.000	13.244	.328	640	1,470	735	7.2898	.9705
15 $\frac{1}{8}$	70	16.000	15.198	.401	790	1,820	910	9.4150	1.2586

* Figures in this column determined by multiplying corresponding values in cubic feet by 7.4805.

Shutting off water at a depth of 3,000 feet is not uncommon in some of the California fields. In fact, in parts of the east side of the Coalinga field the water strings must be set between 3,500 and 4,000 feet deep. The example cited shows that no matter how desirable a safety factor of 3 may be, it can not be generally applied to modern drilling conditions. Therefore, a safety factor of 2 has been tacitly adopted in California practice, and so far has given rather general satisfaction. The factor of 2 is sometimes shaved a little, but the practice is not to be recommended.

One fortunate circumstance is that while a string of casing is being subjected to severe drilling stresses such as pulling, driving, and jarring, the external and internal fluid pressures on the pipe are equalized. Not until the string is landed and the fluid lowered within it is any collapsing tendency developed; thus drilling and collapsing stresses are not coexistent.

As mentioned, the static pressure developed on a water string increases in proportion to the depth at which the water string is set below the natural water level of the locality. Therefore it is unnecessary to have the upper part of the pipe as heavy as the lower part. To illustrate, suppose a water shut-off was to be made at 2,900 feet with 10-inch casing. The string could be inserted in the following sequence and yet have a safety factor of at least 2 at every joint in the string.

Specifications for 2,900-foot 10-inch casing having safety factor of at least 2 at every joint.

Sequence.	Length.	Weight of casing.
	<i>Feet.</i>	<i>Pounds.</i>
1 (bottom of hole).....	560	54
2.....	290	48
3.....	440	45
4 (top of hole).....	1,620	40
Total.....	2,900	.....

Although two weights of pipe are commonly used, and sometimes three, in making up the string, the use of more than three weights is rare. The table of collapsing pressures for different sizes and weights of casing given in Haseltine's paper ^a has been widely used among operators as a standard for determining the proper weights of casing to use for various jobs. Some operators have found by experience that it is advisable to increase the weight of casing with the depth of the hole when the pipe is to be used as a water string. The writer took occasion to ask a successful drilling foreman of wide experience and recognized ability what weights of pipe he would advise using for water strings at various depths. In round numbers his estimates were practically the same as those shown in Table 1 in the column "Water column with safety factor of 2." His estimates were from experience, as he did not use the table for collapsing pressures. This example is cited here to indicate that good practice as developed by experience, involving many costly failures, is in accord with experimental data.

CLASSIFICATION OF METHODS FOR SHUTTING OFF WATER IN OIL AND GAS WELLS OF CALIFORNIA.

In general the methods of shutting off water may be classified under two main headings, as follows:

1. Setting the casing in the formation with or without mud fluid, and with or without a mechanical packer.

^a Haseltine, R. S., Collapsing pressure of steel tubes, West. Eng., vol. 1, July, 1912, pp. 295-297.

2. Setting the casing after cementing material of one kind or another has been placed between the casing and the wall of the hole.

In all probability the landing method of shutting off water has been used ever since the first water string was set. The method depends primarily on locating a stratum that is impervious to water even when the effective thickness is only the length of the casing shoe, perhaps 18 inches. This method when used in connection with mud fluid has been so thoroughly described by Lewis and McMurray* that there is little to be added here. In drilling a well, when it has been decided to case off the top water at a certain stratum the last 10 to 20 feet of hole is drilled smaller, and the casing is then set firmly into it. The weight of the casing is usually sufficient to force the shoe to a good firm seat.

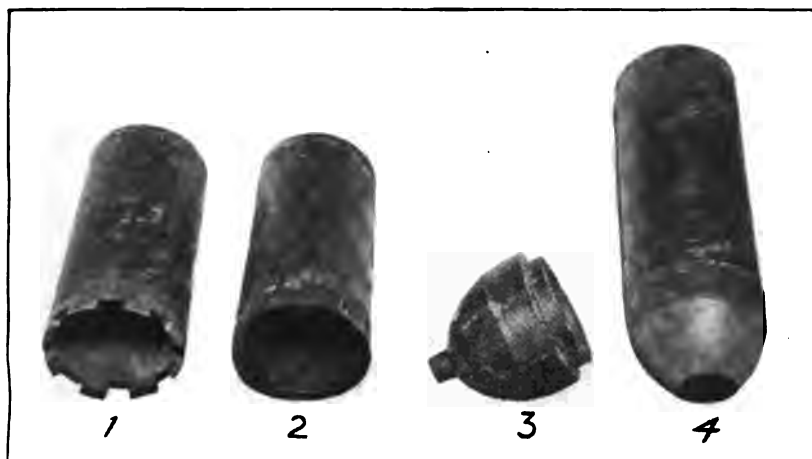
Some operators drive the casing until there is a sharp rebound of the drive clamps. Driving a water string is not advisable, and is seldom done now except where landing has been unsuccessful and the operator is taking his only chance of saving another string of pipe. Even under these conditions he must be careful or he may make a bad matter worse. Of course, this refers only to driving a water string, and has no connection with driving a loggy string of pipe in order to loosen it.

The practice of pulling up a string of casing a joint or two from the bottom, throwing out the calf-wheel clutch, and allowing the casing to race back into the hole in order to seat it firmly, is not to be recommended; such a practice is likely to "pinch" the shoe or bend the casing at or near the shoe joint. The drilling troubles thus precipitated will not be discussed here as they are well known to drillers.

Instead of using a plain casing shoe, various types of tapered shoes and long shoes up to 20 feet in length have been used. The tapered shoe, of course, seats more tightly than a plain one. Plate I, A, shows a plain shoe. An effective form of tapered shoe is used by the Shell Co. of California, in casing its rotary-drilled holes. The shoe is there known as the "McDuffey shoe." It is illustrated in figure 2. This shoe is sometimes referred to as a barrel shoe, as it is tapered at both ends. For convenience in the shop it is made in three rings screwed together. The purpose of the bottom taper is the same as that on any other tapered shoe. The object of the taper on the upper end of the shoe is to give better opportunity for the mud in the hole to settle down and fill any crevices between the shoe and the sides of the hole.

The long shoe is commonly made by putting a sleeve of pipe or protector rings over the shoe joint and turning it down in a lathe to

* Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, 86 pp.

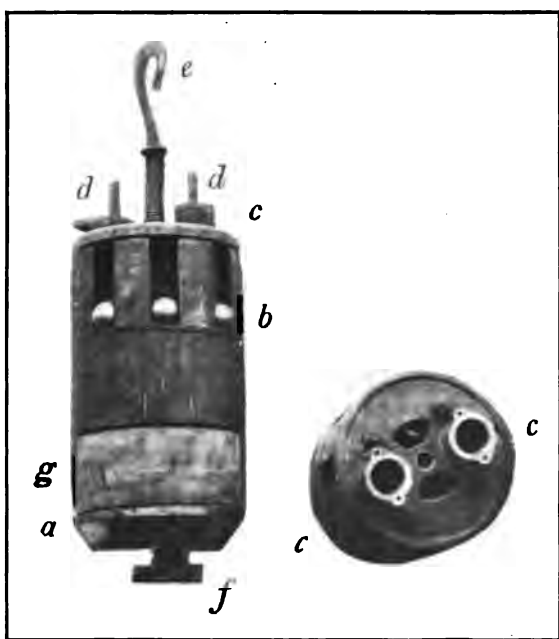


4. CASING SHOES.

1, Baker shoe; 2, plain shoe; 3, "grahm" cast-iron float plug in the rough; 4, plain shoe with "grahm" float plug screwed into it. The casing shoes are made of tempered steel.



B. "SURE-SHOT" CEMENTING PLUG.



C. HALL CEMENT PLUG.

the desired diameter. The purpose of the long shoe is to give greater contact surface between the shoe and the landing formation. Although most strata when in thin layers are somewhat pervious, a fairly thick layer of the same material is frequently entirely impervious to the passage of water. The long shoe is designed to take advantage of such a condition.

It is necessary in nearly all parts of the California fields to keep the hole full of water or mud fluid at all times during the drilling. Drilling with a dry hole is almost unknown. Thus, in drilling through the alternating and rather cavey shales, sands, and clays the fluid becomes somewhat mud laden both inside and outside of the casing, even when only clear water has been run into the hole. When the casing is landed for a "formation" shut-off this fluid tends to settle between the pipe and the walls of the hole and to improve the immediate effectiveness and the permanency of the job. As these conditions pertaining to the use of mud-laden fluid are not at all dependent on whether the casing is cemented or landed, they are present in all types of water jobs and play a more or less important part in shutting off the water. The writer is inclined to believe that the part thus played by the mud is rather more important than is often realized.

If the formation in which the water string is to be set is a "shell," which would ordinarily have to be reamed to let the casing through, the small hole is drilled a foot or 18 inches into the shell and the

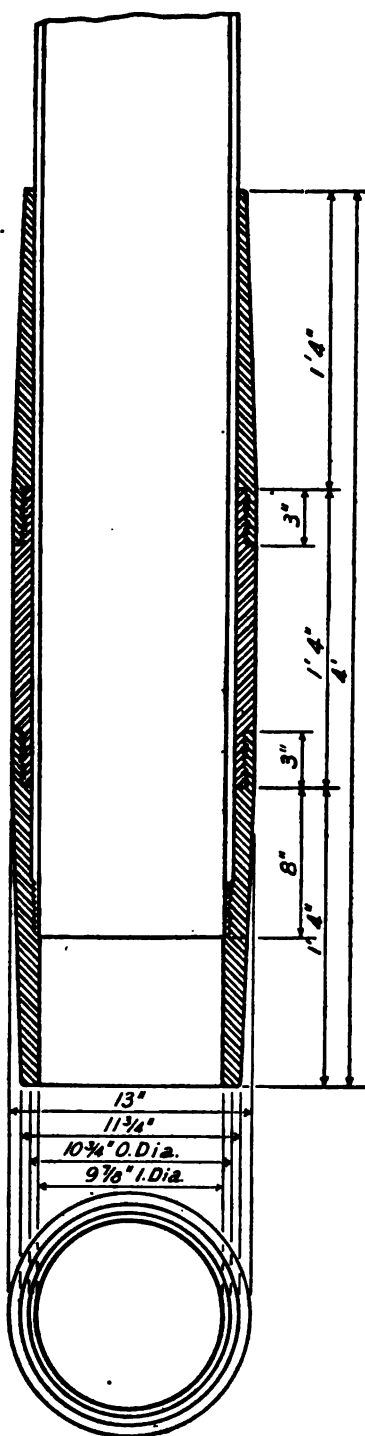


FIGURE 2.—McDuffey barrel shoe.

casing set into it, as described. The driller usually keeps the casing close to the top of the shell when using cable tools, and keeps a tight drilling line, thus making a close hole but little larger than the tools themselves.

This method of landing a water string without cement is little used at present in California fields except in rotary-drilled holes and in shallow territory where there is little water to contend with. As a matter of fact, even in such territory, and also in rotary-drilled holes full of mud fluid, it is usual among the operators to cement the water string. The landing method is described herein chiefly because many producing wells have had their water strings set in this manner, which may be responsible for a considerable share of the water trouble in these fields at the present time.

GENERAL DISCUSSION OF METHODS AND OBJECTS OF CEMENTING.

The second division of methods of shutting off water in the classification adopted herein includes all methods and processes in which cementing materials of one kind or another are used inside the well. The various methods described in the following pages have as their object the placing of the cement between the casing to be cemented and the wall of the hole, and at or near the bottom of the hole so that the casing may be landed on bottom, thus preventing the liquid cement from running back inside the casing. The quantity of cement used on a single job varies from one-half ton to 30 tons (2,000 pounds per ton). Sufficient time, usually 10 days or 2 weeks, and in exceptional instances a month, is allowed for the cement to set. At the expiration of the setting time work on the well is resumed. The first work to be done is to test the effectiveness of the cementing job. The California law regulating water shut-offs and other phases of the oil industry is presented on pages 97 to 115.

There are several advantages to be gained by cementing, as follows:

If the casing is set in a hard stratum there is every chance for the cement to fill closely all irregularities between the wall of the hole and the casing, thus preventing water or other fluid from passing around the shoe of the water string to the interior of the well.

The cement may be forced several hundred feet up behind the casing, thus holding it firmly in position and reducing the possibility of its being bent by unequal settling of the walls of the hole, or of being dented by a boulder sloughing in against it. Two instances will suffice to show how far cement may be forced with pumps up behind a string of pipe. At a well in the west side of the Coalinga

field a string of 8½-inch casing was cemented at 1,100 feet, with 248 sacks of cement pumped in by the tubing method. The cement was pumped up behind the casing until it came out at the surface. At another well in the Buena Vista Hills district of the Midway field the water string had been cemented at about 3,000 feet. When the well was abandoned and an attempt made to recover the upper part of the water string after the bottom had been plugged, the water string was found to be cemented to the next larger string of pipe, the shoe of which was at about 2,000 feet. Thus the cement had risen 1,000 feet outside of the water string.

Many operators cement water strings in a rotary hole even where it is generally assumed that the mud will be sufficient to make a water-tight job without the use of cement. The purpose of this practice is more to reinforce and support the pipe than to perfect the seal. Also, it is hoped that the cement will retard deterioration of the casing from corrosion. The operators believe that this use of cement is somewhat like carrying fire insurance on a building. A well is a costly improvement to a piece of property and is worth protecting, as the loss to the operator if water breaks into the well and destroys a valuable oil sand would exceed the cost of the well many fold. Sometimes such a hole can be plugged and the destruction arrested, but owing to lost tools or casing, or to a crooked hole, it may be mechanically impossible to plug the hole properly. It is the old story of the ounce of prevention versus the pound of cure.

Another important advantage in cementing a water string is in filling up between the casing and the wall of the hole with a material that takes its initial set within a day or two. A firm mass is thus built around the casing which, though it may not make a perfectly water-tight bond either between itself and the casing, or between itself and the formation, will afford the mud and cavings an excellent opportunity as they settle in the hole to seal every crevice and pour in or around the cement mass. The cement thus acts like a nonrotatable wall packer, affording the mud the best possible chance to do its work.

The value of cement as a safety factor on a water shut-off is well illustrated at a well in the Sunset field. This well was sunk with a rotary drill to approximately 2,400 feet, and the 10-inch casing was set with no other casing in the hole. The driller stated that the last 20 feet of the hole had shown a little gas and oil in the shale. It would have been extremely difficult to have plugged such an open hole 20 feet from the bottom and have the plug solid enough to cement on it, as the hole would probably have caved in before the job could have been completed. Moreover, the "showing" seemed insignificant, and the casing was not to go through the oil-bearing shale, but merely to extend into it for 20 feet. Accordingly the casing was put

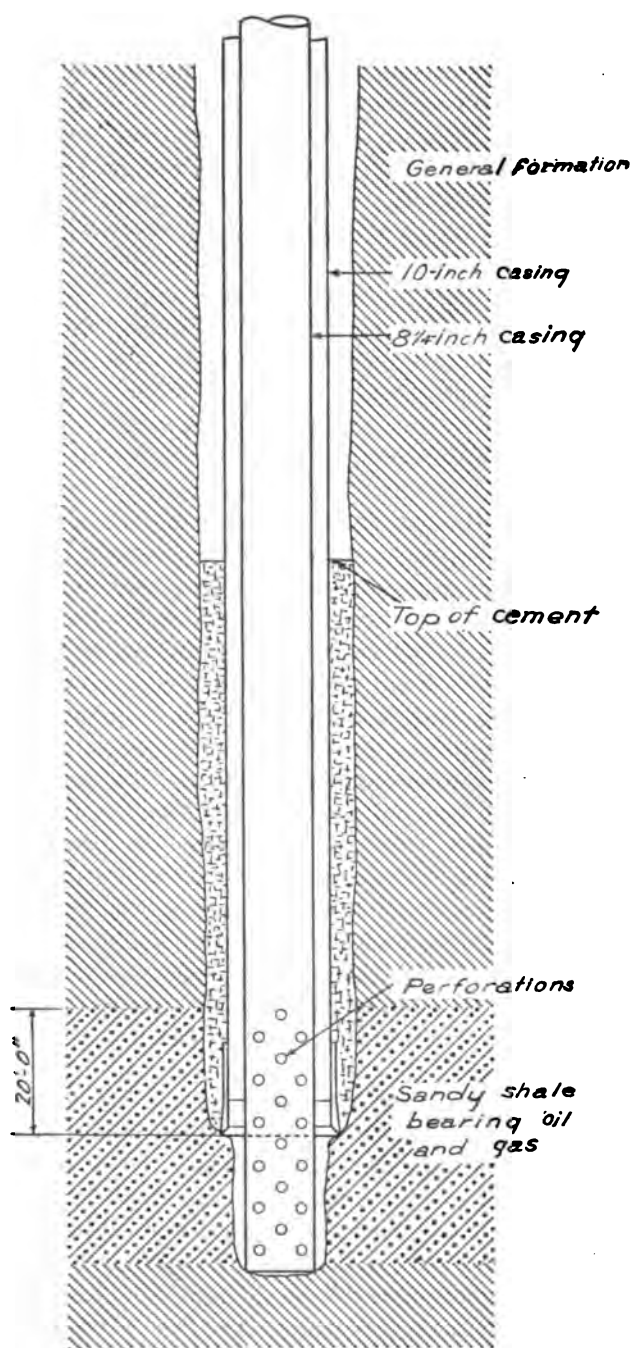


FIGURE 3.—Well in Sunset field in which water string extends 20 feet into oil-bearing stratum, yet the cement successfully shut off water in shale above.

in and cemented by the "Perkins process," 4 tons of cement being used. (See fig. 8.) Further work demonstrated that this oil-bearing shale was about 40 feet thick and constituted the only pay stratum penetrated by the well. Incidentally the well proved to be a good producer for that locality, and no water troubles were encountered. The cement had evidently been forced up behind the pipe and made a shut-off above the oil-bearing shale, leaving the bottom joint of the water string extending 20 feet into this formation without letting any water into it.

One more noteworthy instance may be cited from the Buena Vista Hills of the Midway field. There a well flowed for about two years, making several hundred barrels of clean oil daily. Finally production ceased, and when cleaning-out tools were run into the hole, it was found that both the oil and the water strings were bent near the bottom of the water string. The oil string was pulled, but parted near the bottom of the 6½-inch water string. The two lower joints of this 6½-inch string were ripped off and drilled up to straighten the hole. Fearing that this work might have broken the cement outside of the remaining part of the water string, the company had the water bailed out of the hole to the 1,800-foot level. For several hours there was no change in the water level. As the string of 6½-inch pipe was holding back flowing water, the test was believed to be adequate. Additional evidence of the efficiency of the cementing was furnished later when the redrilling was completed, as the well again became a producer of clean oil. It is interesting to note that this water string had been cemented with only 35 sacks of cement, which had been placed with a dump bailer such as that shown in Plate II, for by this method the cement is not forced as high outside of the water string as can be done by a pumping method.

The two instances cited will suffice to show the value of making a water shut-off as permanent as possible whether the danger of top water is seemingly small or is great. In fact, it has been the experience of the Bureau of Mines engineers that water conditions where comparatively easy to overcome may be overlooked and neglected.

DUMP-BAILER CEMENTING PROCESS.

GENERAL REMARKS.

In cementing a string of casing with the dump bailer, the liquid cement is lowered to the bottom of the hole with a bailer which, as its name indicates, discharges or dumps its load instead of picking it up like the ordinary bailer. By this method 2 or 3 tons of cement is dumped into the bottom of the well. As many runs are made with the bailer as may be necessary to deposit the entire quantity of cement to be used. The required quantity can almost.

never be lowered in one load. After this is done, the casing is pulled up 20 to 40 feet off bottom, or so that the shoe will be above the cement level. The casing is filled with water and then closed at the top with a steel plug, or other suitable fitting, and is lowered firmly to the bottom of the hole. There being no outlet at the top of the casing for the water, the cement can not enter at the bottom, so it takes the only open course and rises outside the casing, filling the space between the casing and the walls of the hole.

DESCRIPTION OF DUMP BAILER.

There are several types of dump bailers in use; also, there are several ways to transform an ordinary dart bailer into a makeshift dump bailer, but such makeshifts are unsatisfactory and likely to cause trouble. A satisfactory type of dump bailer is the one shown in Plate II. The shell of this bailer is of two joints of pipe swaged to connect in a coupling of the same external diameter as the joints. As the bailers vary in size according to the size of casing in which they are to be used, dimensions are omitted here. The bail *a* terminates in a bottle neck through which the rod *b* is free to slide. The enlargement at the lower end of this rod is bored as a rope socket to receive the $\frac{7}{8}$ -inch wire dump line *c*. The rod is provided with a latch *d*, in general design similar to that on the shaft of an old-fashioned umbrella. The upper end of the rod is threaded to screw into the bottom of a tool joint. This joint has a pin on its top to make up with the box of the rope socket so that the dump bailer may be run on the drilling line. Riveted to the bottom of the bailer is an annular steel valve seat. The valve *e* is of steel and in the form of a truncated cone. Of course, a ball would do the work as well as the cone. The wire line, or chain if preferred, which connects the rod *b* with the cone, must be babbitted, or otherwise securely attached to both rod and cone, as the entire weight of the bailer and contents must be carried by the dump line or chain. It is worth noting that if either of these two babbitted connections fail, only the cone, or at worst the cone and the dump line, will be left in the hole, as the shell of the bailer will hang on the butt of the rod *b*.

When this bailer is run to bottom, the rod slips down through the bottle neck in the bail, thus throwing about 3 feet of slack in the connecting cable. When the bailer is lifted again the latch engages with the bail and the entire device is brought to the surface with the valve dangling about 3 feet below the valve seat. There is thus no possibility of the bailer not discharging its contents. In running such a bailer in a hole full of fluid it tends to float if lowered too rapidly. The latch will then trip the bailer and discharge the contents. Such an accident is particularly apt to occur when the fluid level is

DUMP BAILER.

several hundred feet below the surface. Such premature unloading may take place without the driller's knowledge and go undetected until the job is found to be unsuccessful. All this trouble will be avoided by care in lowering the bailer slowly enough, allowing no slack in the drilling cable. In the type of construction illustrated in Plate II, more than two joints of pipe may be used if so desired.

METHOD OF USE.

In order to reset the latch for another run, the shell of the bailer must be supported and the rod lowered enough to allow the latch to be pushed into the rod and so held until the rod is pulled up through the bottle neck. This can be done more conveniently with the top of the bailer near the derrick floor than by resting the bottom of the bailer on the floor. A convenient method is to have two pieces of timber 4 by 6 inches by 2 feet coped to fit the bailer, with two long bolts connecting their ends. By drawing the bolts tight the wood clamps will grip the bailer and, resting on the top coupling of the casing, hold it while the latch is set. The bolts may be loosened and the bailer lowered through the clamps, which are then in place when the bailer is again raised through them.

The dump-bailer method is frequently used when a water string is to be set with a relatively small amount of cement, say, less than 2 tons. The cement is mixed in a box on the derrick floor in batches according to the capacity of the bailer. After cement has been wet, it should not be held over for the next batch. Surplus cement, after the bailer has been filled, should be discarded. A convenient rule is to figure that each sack of cement when mixed will occupy 1.15 cubic feet. This, of course, allows for the excess of water used to obtain the necessary fluidity, as well as to prevent the cement from taking its initial set too quickly.

The bailer latch is set and the bailer hung in the hole with the shell seated on the cone valve *c* so that the top of the shell comes level with the floor and under a spout or swing pipe leading from the cement box. The bailer is then loaded and run to bottom in the manner described. It is advisable to have a bailer large enough so that the period from the time the first batch of cement is wet until the job is completed will not exceed two hours. It is important to have enough men with hoes at work to insure that the mixing of each batch is commenced as soon as the last of the preceding batch has left the mixing box, and that the mixed cement will not have to be kept waiting for the bailer. Frequently, while a driller and tool dresser are lowering and dumping a bailer, pulling out and resetting the latch and getting the bailer in position for the next charge of cement, the other men get the cement ready to pour. This is the ideal arrangement, but one dares not speed up the bailer movements

to any great degree, and as more than five hoes in, say, a 10-sack mix, does not accelerate mixing, the controlling time factor is the depth of the hole. Nevertheless, when cementing a deep hole care can be taken that the mixed cement does not have to wait for the bailer. If the dry cement is piled into the high end of the mixing box away from the outlet, and a nozzle be used on the water hose so that a high-pressure stream of water may be played back and forth across the box impinging on the pile of cement so as to cut and mix it in slices 2 to 4 inches thick, the cement not only mixes more quickly, but with fewer lumps, and consequently requires less hoeing than if mixed entirely with hoes.

During cementing, the hole should be kept full of water, if possible. After all the cement has been dumped, the casing is filled with water and set, as described. The well should be left undisturbed at least 24 hours before the pressure within the casing is released. After this time it is advisable to stretch the casing as much as experience has shown is allowable. The casing is then hung on clamps in this position so that it is held both at the top and the bottom; otherwise the pipe tends to bend from its own weight.

CEMENTING PLUGS AND THEIR USE.

Occasionally it is desirable to cement a hole that can not be filled to the top with water, as the water runs away in a sand that has a natural water level some considerable depth below the derrick floor, so that all the available water that can be run into the hole will not raise the natural water level, nor continuous bailing greatly lower it. The best solution for such a problem may be to use one of the other cementing methods described in subsequent pages.

Sometimes equipment for the other methods is not available so that the dump bailer must be used. Again conditions may arise that make it undesirable to pump large quantities of cement back of the casing. The chief difficulty of cementing with the dump bailer in a hole in which the natural water level is low is that after the cement has been mixed and placed there will be an air column above the water in the casing. This air will compress as the casing is lowered, thus allowing the cement to remain at practically the same level inside the casing as outside. Moreover, if the casing has been set on bottom, filled with water, and the fittings put on, when the casing is lifted the water will immediately run out, washing the cement away from the bottom of the pipe. Of course, the height of water column that would be required to give sufficient weight to force the cement up back of the casing and still not entirely out of it, could be calculated. Such a calculation is necessarily based on numerous fundamental assumptions, and the results are untrustworthy.

"SURE-SHOT" CEMENT PLUG.

For cementing a hole in which the water level is low, a device such as the "sure-shot cement plug"^a (Pl. I, *B*, p. 22), or the "Hall cement plug"^b (Pl. I, *C*), may be used. These two devices are for identically the same purpose, that is, to tightly close the bottom of the casing to be cemented after the cement has been dumped through the casing into the bottom of the hole so that when the casing is lowered into the liquid cement the plug will not allow any cement to reenter the casing, but will force it up on the outside. In other words, these plugs are designed to do the work of the column of water and the tight head, previously described. With the exception of a few small parts, both of these plugs are made of thin cast iron so they can be easily drilled up after the cement has set.

The sure-shot plug (Pl. I, *B*) is lowered into the hole by attaching the eyebolt at the top to the dart of the bailer. If the water resistance tends to stop the passage of the plug, the weight of the bailer will push down on the eyebolt, thus opening the valve in the bottom of the plug, permitting the water to flow through the plug. The plug has in its shell four slots through which may slide stove bolts that hold the lugs to the body of the plug. This construction will be clear by inspection of Plate I, *B*. There is no spring tending to close the valve at the base of the plug. This is done by the weight of the casing. The casing is lifted till the shoe is clear of the cement before the plug is inserted. On passing out of the casing the slips slide down the conical shaped body of the plug resting firmly on the base at *a*. When the bailer is picked up, the slips will be pulled up firmly under the casing shoe and stopped in this position, thus plugging the bottom of the casing, which is then set on bottom, displacing the liquid cement. A quick jerk with the sand line will pull the eyebolt out of the cast poppet valve, and thus release the bailer which pulls the eyebolt with it to the surface.

This plug may not make a water-tight joint at the shoe, and a little cement may work back into the casing, though the writer has never heard of such an occurrence, and is of the opinion that any such leakage will be negligible. Such a small leak as might be afforded between this plug and the shoe will generally be stopped when the plug and shoe are forced into the landing formation by the great weight of casing. This plug is characterized by extreme simplicity of construction, and can be moved up and down in the casing as occasion may necessitate until such time as it has reached its destination. Not until such destination is reached does it become impossible to pull the plug back to the surface.

^a Patented by Carl Baker, of Coalinga, Cal.

^b Manufactured by the Bunting Iron Works, of Coalinga, Cal.

HALL CEMENT PLUG.

The Hall cement plug (Pl. I, *C*) is attached to the dart of the bailer by the eyebolt *e* and pushed down the hole in exactly the same manner as the Baker plug. The valve in the bottom is opened by the pressure of the bailer on the eyebolt extending through the center of the plug.

There are two sets of steel balls which act as slips. The set *b* shown in the longitudinal grooves in the main body of the plug prevents it from being pulled or pushed up the casing. The other set of balls are much smaller diameter and placed in the ball cups *c* around the vertical rods *d*. These rods are firmly attached to the base of the plug *a* and extend upward through the ball cups *c* on the cap of the plug. As the longitudinal grooves are deeper at the upper ends than at the lower, the balls in them rest against the casing at all times and wedge between the casing and the inclined grooves at the first upward movement of the plug. This upward movement is occasioned by a pull on the eyebolt when the plug has reached its destination. The eyebolt being attached to the valve *f* closes it and at the same time pulls up the base *a*. This squeezes the rubber *g* tightly against the casing, making a water-tight contact. The balls in the cups *c* grip the rods and so hold them that the base *a* can not slip away from the main body of the plug, thus holding the rubber firmly in its compressed position.

Care must be taken to have a suitable and substantial mark on the sand line so as to stop the plug in the bottom joint of the casing and yet not let the plug leave the pipe. If this plug is run below the casing in all probability it will hang on the edge of the shoe and can not be pulled back into the casing. Even if by chance it should start back into the casing the balls at *b* would prevent its getting high enough to allow the rubber *g* to set in the pipe. After the plug is lodged in the pipe, the string is lowered to the bottom just as with the sure-shot plug.

With the Hall plug there will always be 5 to 10 feet of cement in the casing beneath the plug, as to attempt placing the plug closer than this to the shoe would entail risk of getting it below the casing. However, there should be no difficulty in drilling out such an amount of cement. When using this plug a driller must remember that after it has once started into the casing there is no chance to pull it out without drilling it up, as to pull it back as much as 6 inches sets it so that it will go neither up nor down.

TUBING METHOD OF CEMENTING.

The tubing method of cementing casing in wells is subject to many variations and modifications. The essential features are that the liquid cement enters the well through tubing usually 2 to 3 inches

in diameter which extends to within a few feet of the bottom, inside of the casing that is to be cemented. Some provision must be made to prevent the cement from backing up between the tubing and the casing, and to force it to go up between the casing and the wall of the hole. For this purpose a packing device of some kind is used which seals off the annular space between the tubing and the casing. The packing device may be placed at either end of the string of tubing or at any intermediate point. For mechanical convenience it is customary to put the packing device either at the bottom or the top of the tubing.

In cementing a well by the tubing method the driller should make sure that fluid will circulate before any other work such as putting in tubing is started. If water can not be forced from inside of the casing around the shoe and up outside of it, it is obviously useless to try to force cement through. Assuming that it has been possible to get circulation with water or mud fluid, the tubing may be inserted with the packer on the bottom. A disk packer is frequently used for such jobs, although any other type of packer meeting the general requirements will do. The cement is mixed and pumped by the method described under the discussion of the upper packer, or tight-head method of cementing with tubing, on pages 34 to 37. After the cement has been mixed and pumped in under the packer and followed by sufficient water to flush the tubing clear of cement, a stopcock, or gate, at the top of the tubing is closed, and the casing is lowered to the bottom of the hole. After the casing is thus set on bottom, the tubing, together with the packer, should be pulled up enough to free the packer before any residual cement has an opportunity to set. After the packer has been thus loosened, water is pumped down the tubing and back to the surface between the tubing and the casing in order to wash out any cement from inside the casing. The tubing is then pulled out, bringing the packer with it. This done, it is advisable to completely fill the casing with water and close the top with a plug or other suitable fitting, and to leave the hole in this condition while the cement sets. In fact, a column of water should be kept inside of the casing after any cementing job in order to counteract the tendency of the liquid cement to run back into the casing through any stray channel under the shoe. Some operators go so far as to set a pump to hold a certain water pressure on the casing, perhaps 50 pounds per square inch or more, as may be required. The pump is watched and is so regulated as to counteract any leakage in the fittings and to maintain a steady pressure on the well.

The disadvantage of the bottom packer is that it may leak cement under high pressure and by-pass so much of it above the packer that the packer can not be pulled. The operator will then have to drill the

cement and the packer out of the bottom of the water string, with perhaps a joint or two of tubing. To avoid the possible loss of tubing there should be a left-hand thread connection between the tubing and the packer. Even though sufficient cement may have been forced outside of the casing to make a water-tight job, the severe pounding of the tools while drilling up cement and junk will probably crack the outside cement and may even tear a hole in the water string itself.

This disadvantage has been overcome by omitting the packer at the bottom of the well and using one at the top instead.^a There are several top packing devices in use. Two forms of top packers, or tight heads, as they are commonly called, are shown in Plates III and IV. Another form is shown in Plate V, A.

In addition to changing the position of the packing devices, there are several variations in the method of mixing and pumping the cement into the tubing. One of the best systems in use is that operated by William F. Scott, of Taft, Cal.

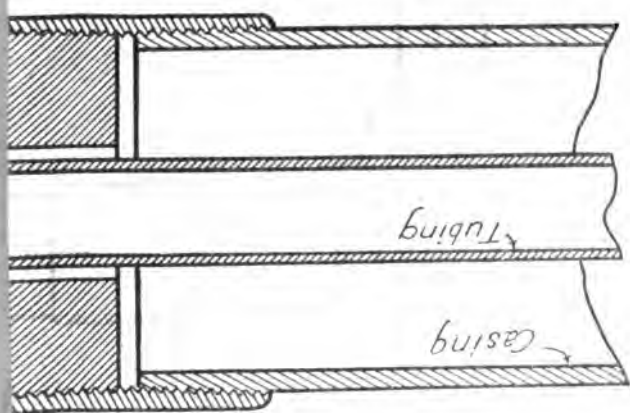
CONSTRUCTION AND OPERATION OF SCOTT CEMENTING OUTFIT.

As shown in Plate VI, the Scott outfit is mounted on a stout wagon to facilitate its transportation. It is hauled by team or motor truck to a convenient position near the well to be cemented. The main features of the outfit are the wagon, water tank, cement mixer, single-cylinder steam engine to drive the mixer, cement pump, small suction tank, and top packer or tight casing head.

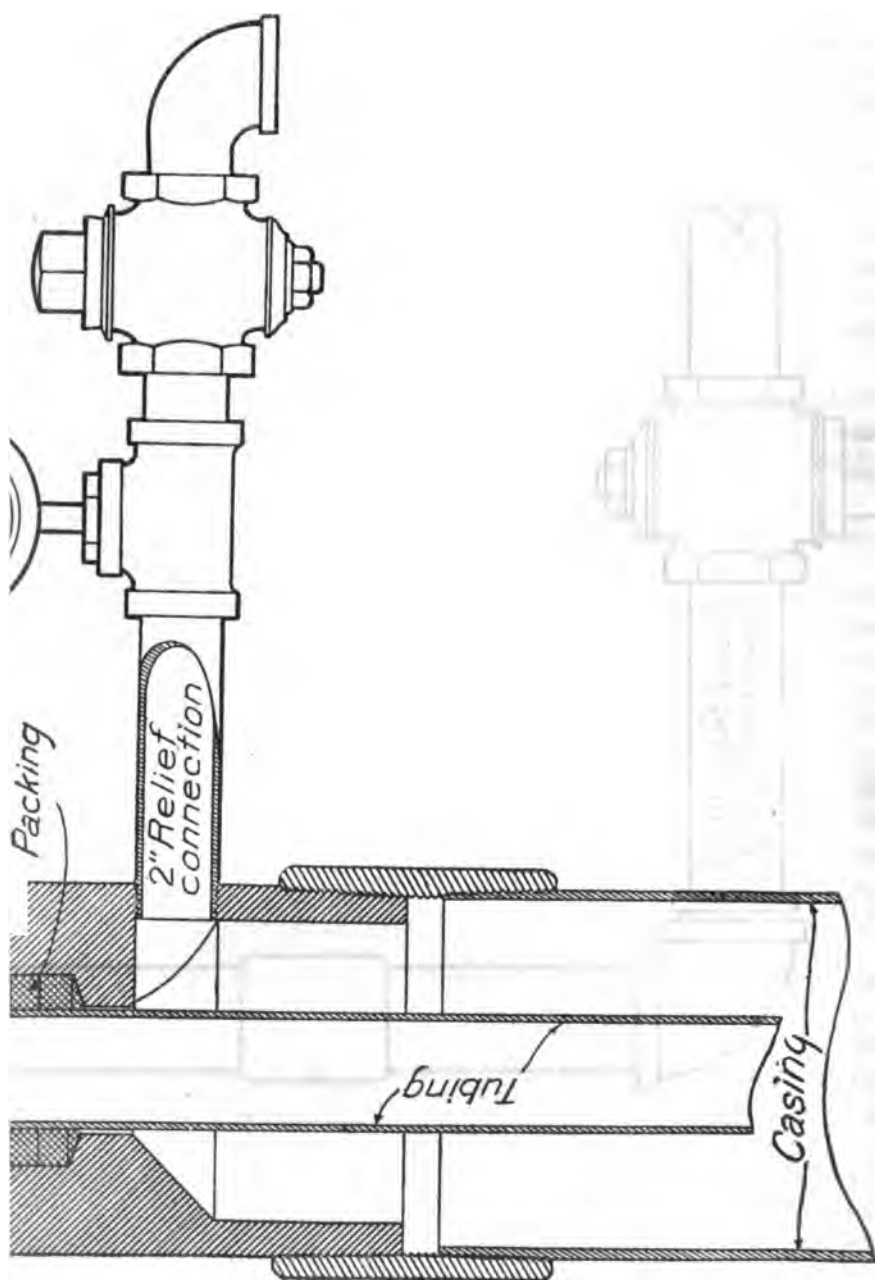
The water tank is a galvanized-iron tank of convenient size, securely mounted on the rear of the wagon and fitted with a 3-inch flange in the bottom connected to the 3-inch suction line to the pump. This line has a 2-inch intake from the main water-supply line, and also has a 2-inch branch discharging into the top of the tank. This tank is used for gaging the water pumped after the cement.

The cement mixer was built by Mr. Scott according to his own design. The mixing barrel is a piece of 12½-inch casing about 6½ feet long with a feed hopper as shown in the illustrations. This hopper feeds the dry cement to the mixing barrel below. The feed is regulated by a sheet-iron door operated by a lever *a* (Pl. VI, A). To insure uniform feed and to break up any lumps in the dry cement, thus preventing it from clogging in the hopper, there is a shaft fitted with radial iron pins. The pins are about 3 inches long, made of ½-inch round iron. The end of this shaft and its drive sprocket are shown at *b*. This sprocket is chain driven from a jack shaft, which is in turn driven from a sprocket on the main-line shaft of

^a See Wiggle, W. P., Method of cementing walls of a hole: U. S. patent 1067789, Apr. 1, 1913.



HONOLULU CEMENTING HEAD.



CEMENTING HEAD OF STUFFING-BOX TYPE.

the mixer, thus causing the small feeding shaft to rotate at a greatly reduced rate of speed compared to the speed of the line shaft.

The end of the mixing barrel under the feed hopper is closed by an ordinary cap to fit $12\frac{1}{4}$ -inch 10-thread casing. In the cap are three holes. The central hole admits the drive shaft, and acts as a bearing for it. The other holes, one on either side of the center, admit water into the mixing barrel. The two intakes provide a more uniform distribution of water than would be possible with only one. The line shaft is flanged directly to the engine shaft, thus gaining strength, simplicity, and compactness by a straight-line drive. The bearing at the discharge end of the mixer is held by a semicircular cap as shown in Plate VI, *B*. This cap is held in place by three cap screws, and thus can be easily removed. The cap screws also permit accurate centering of the line shaft when adjustments may be necessitated from the replacing of broken mixing blades. The small three-bolt shaft coupling shown at *c* (Pl. VI, *A*) may be disconnected and the adjacent sprocket taken off, thus leaving the line shaft free to be removed for cleaning and repairs.

The 2-inch line shaft has a set of cast-iron mixing blades (Pl. V, *B*) mounted on it. These blades are cast with lugs on one side of the hub and notches at 90° to them on the opposite side. When a set of blades are slipped on the shaft the notches on the one will mesh with the lugs on the next adjacent hub, thus each successive blade is held at 90° to the one preceding it. Such an arrangement causes the entire set to rotate as a unit without any radial slip. Two blades at each end of the set and one or two in the middle are attached to the shaft with set screws. This construction permits the easy and quick replacement of broken blades and obviates any machine work on them except that necessitated by the set screws. The blades being of cast iron may break if a large nut, bolt, or other piece of iron gets into the mixer by accident along with the cement. It is far better to have a broken blade in the mixer than a shutdown in its operation. Obviating a shutdown after the mixing of cement has once started is most important, as the wet cement would not only have opportunity to set in the mixer, but delay might mean failure of the entire cementing job. The mixing blades are about $6\frac{1}{8}$ inches long from the center of the hub to the periphery. The pitch of the blades is such that as one looks into the discharge end of the mixer the shaft must rotate in a clockwise direction. This direction of rotation tends to clear the cement away from the bottom of the feed hopper.

If the main shaft of the mixer rotates at 400 revolutions per minute, a ton of cement (20 sacks) can be mixed in $2\frac{1}{4}$ to 3 minutes. The cement passes through the chute at the discharge end of the mixer into small suction tank *d* (Pl. VI, *A*), from which it is taken directly by the pump and forced into the well without the necessity

of working it at all with hoes. The mixing is entirely mechanical, thus reducing labor and accelerating the process.

The engine used is a single-cylinder, $4\frac{1}{2}$ by 5 inch, Clark steam engine, and gives entire satisfaction.

A 10 by 4 by 10 inch Snow duplex pump is used to force the cement into the tubing. This pump will deliver at about 750 pounds gage pressure.

A small galvanized-iron tank of about 20 cubic foot capacity is used as a suction tank. Almost any strong tank or box of 10 to 20 cubic foot capacity will do for the purpose. The tank should not, however, be of a low squatty design. The object is, of course, that the suction tank carry as small a quantity of cement as possible so it will be drawn off by the pump as fast as it is mixed, allowing no time for any settling to take place in the suction box.

The top packer, or tight head, is designed in many forms.

Plate V, C shows the tight head used by Mr. Scott when cementing a string of 8 $\frac{1}{4}$ -inch casing. The sack wrapped around the tubing is more to illustrate the necessity of packing than to recommend the method illustrated. Ordinarily when this head is used a steel plate bored to take the tubing is slipped over the last joint before it is set up. This rests under the top coupling of the tubing and presses soft hemp or other packing into the annular space between the tubing and the tight head.

Plate V, A, shows a tight head used successfully in the Coalinga and Sunset fields.* This head is bored to allow passage of the 3-inch tubing, but not a coupling, and must therefore be slipped onto the last joint of tubing before the latter is set up. The head is then screwed into the top coupling of the casing to be cemented. The rim of the hole through the casing head has a small bevel turned around it to receive a ring of hydraulic packing that is put around the tubing and under the coupling. The follower plate may be drawn firmly down on top of the coupling by the stud bolts if necessary.

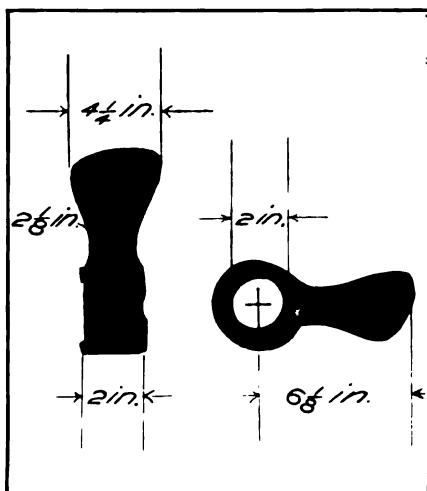
Some operators in the Midway field have had difficulty with various types of tight heads that require packing to make a tight joint between the tubing and the casing head. The trouble was occasioned by leakage around the packing toward the finish of the cementing job, when the highest pressure is naturally used. To get around this difficulty the Honolulu casing head shown in Plate III (p. 34) was designed and has proven satisfactory. In this head the packing is replaced by threaded connections.

In using either the Honolulu or the Southern Pacific Co. head, the tubing must be lifted in order to provide a relief vent for washing surplus cement out of the tubing and casing after the tubing has

*Made and used by the fuel department, Southern Pacific Co.



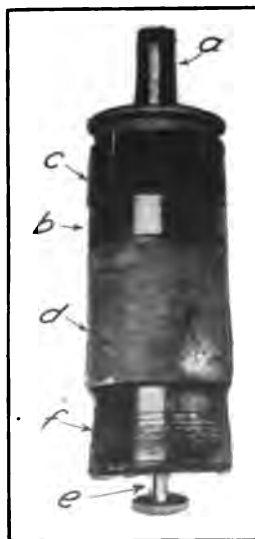
A. CEMENTING HEAD, KERN TRADING OIL CO.



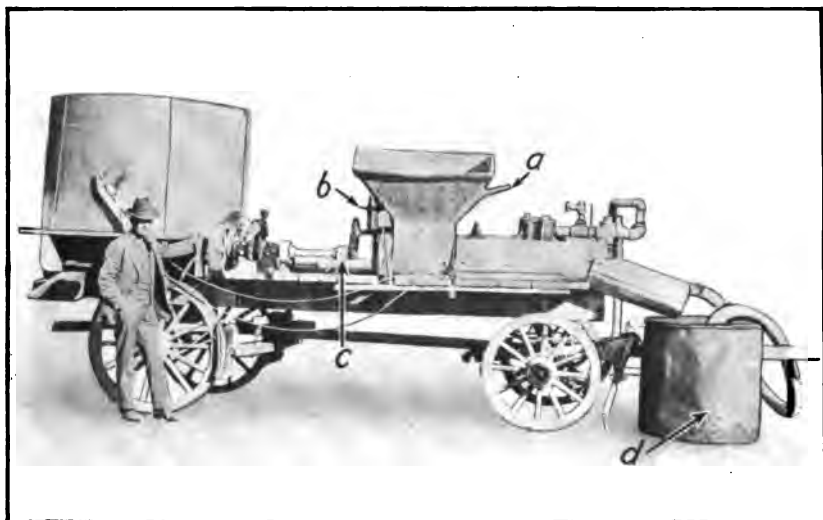
B. MIXER BLADES OF SCOTT CEMENT-ING OUTFIT.



C. SCOTT TIGHT HEAD.



D. BAKER CEMENT CONTAINER.



A. SCOTT CEMENTING OUTFIT, VIEWED FROM SIDE.



B. SCOTT OUTFIT; VIEW OF DISCHARGE END.

been landed. With a Scott head this operation is accomplished by opening the 2-inch stopcock near the pressure gage.

The tight head of the stuffing-box type (Pl. IV, p. 35) consists of a stuffing box and follower drawn down by two $\frac{3}{4}$ -inch stud bolts. The tubing will work through this gland, or, if preferable, a coupling may be set on top of the follower, thus pressing the packing more firmly together, as shown in the drawing. With this type of head it is not necessary to set the weight of the tubing on the follower gland to compress the packing, hence the bottom of the tubing may be set at any desired depth without regard to the position of couplings at the surface. It is believed that this form of stuffing box if thoroughly packed will prevent leakage under the most severe conditions.

CONDITIONS UNDER WHICH TUBING METHOD IS USED.

The tubing method is applicable to cementing water strings that are not likely to "freeze" on standing while the tubing is being inserted. In general, the usual practice is that the tubing method is not used in the hole where mud flush has been circulated during drilling. Like every other generality, this one has exceptions. For instance, one of the large companies in the Midway field used the tubing method in cementing water strings in a rotary-drilled hole. When this company has finished making the hole and is ready to set casing, the drill pipe is pulled out and the tubing stood in the derrick before the casing is started. The tubing may then be inserted far more quickly after the casing is all in the hole than would be possible if it had to be inserted by single joints.

CEMENTING BY TUBING METHOD WITH SCOTT OUTFIT.

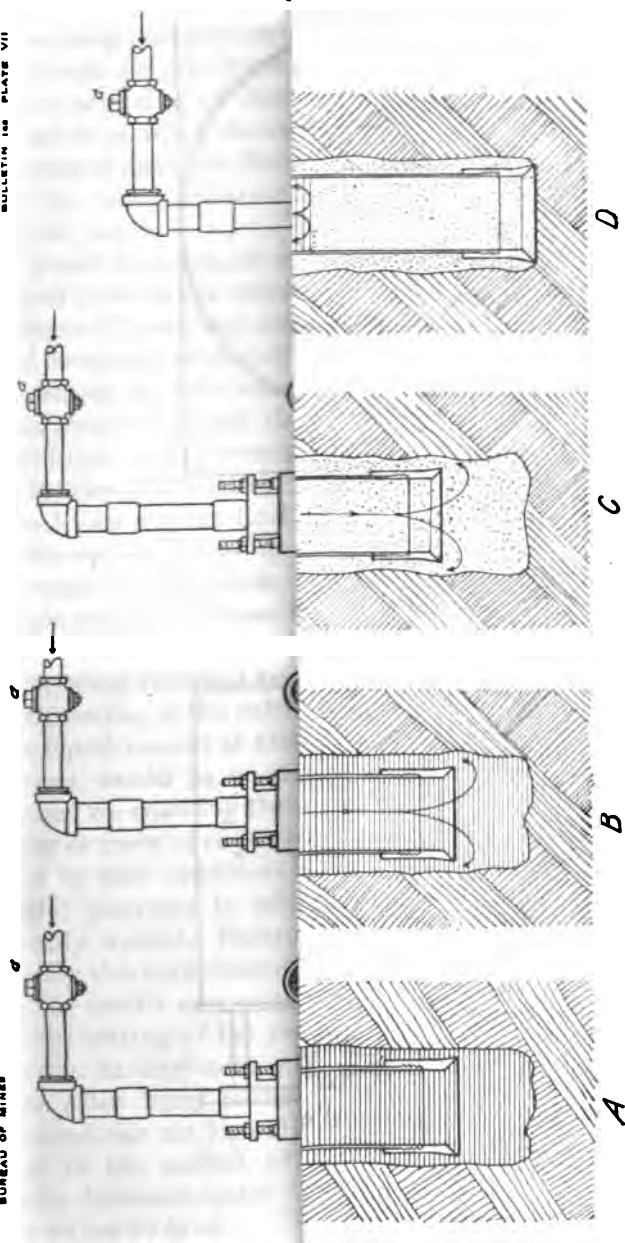
The Scott cementing equipment is used in connection with the tubing method, but the mixing and pumping mechanism may be and, as a matter of fact, is used for cementing without the use of tubing.

In cementing with the Scott outfit the first step, as in all other tubing methods of cementing, is to get circulation. This is done either with pumps at the well or with the cementing pumps. Sufficient water must be stored in temporary tanks at the well to mix the cement and to displace all the cement from the tubing, and more water than this, either in tanks or in a reliable pipe-line system, is desirable for reasons given later. The outfit is set up near the derrick and connected with the local steam and water supply lines. A small platform is built beside the mixing machine with a walk to the ground. This must be so arranged and the dry cement so placed that there will be no delay in feeding the mixture. As stated, this machine handles a ton of cement, or 20 sacks, every $2\frac{1}{2}$ or 3 minutes; that is, a sack every 8 or 9 seconds. All wires or strings must be taken

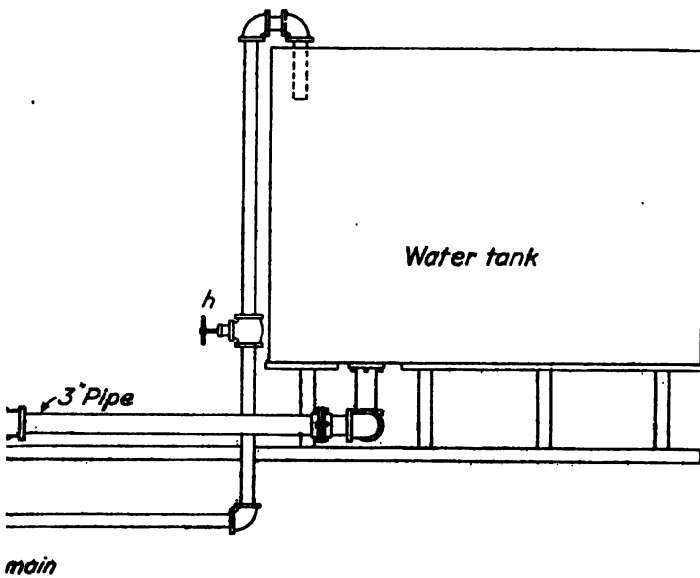
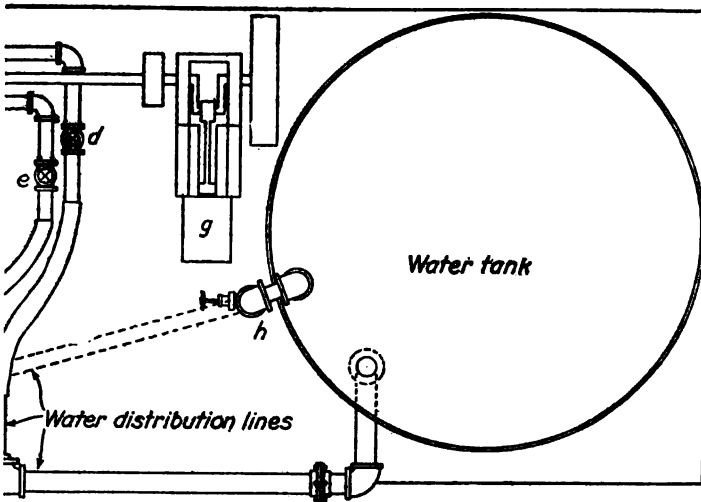
off the sacks before mixing is started. It has been found advisable to have the cement handled by four men, two working at a time and relieving each other at frequent intervals. If more than two are dumping cement at a time they will get in each other's way and retard rather than accelerate the work. When everything is in readiness, clear water is pumped into the tubing at *a*, Plate VII, until returns flow from the relief pipe *b* at the casing head. The relief cock is then closed with the pump still operating and with the casing 3 or 4 feet off bottom. This should start the circulation around the casing as shown in view *B*, Plate VII. Water is then started through the mixer by opening valves *e*, *d*, and *a*, Plate VIII, and closing stopcock *b*. The mixing engine *g* and the pump are started and the dumping of cement into the hopper is commenced. The most satisfactory consistency for the cement mixture is determined by experience. If the mixture is sufficiently thin to be readily handled by the pumps it has an excess of water. A cement should never be mixed any thinner than this unless an effort is being made to force it back into a sand, or some other such object is in view. Even the thickest mixture that can be handled by the pumps has a considerable excess of water. This method of estimating the fluidity is rough, but satisfactory. A small excess of water doubtless retards the setting of the cement, but does not weaken it to a dangerous degree.

Before actual cementing is commenced, a computation must be made so that the operator will know how many inches of water must be pumped out of the gage tank to equal the volume of the string of tubing. If the gage tank regularly mounted on the outfit has insufficient capacity for any particular job, an auxiliary tank must be set. If such an auxiliary tank is placed near enough to the pump the water may be drawn from it by merely dropping the 3-inch suction hose into it, thus reducing the amount of pipe fitting. After all the cement has been mixed and pumped into the tubing, the computed volume of water with usually a small excess, 10 per cent or less, is pumped on top of the cement (*C*, Pl. VII). This is accomplished by closing *c* and *h* (Pl. VIII) and gaging the water in the tank at the same time. In this way the water passes through the mixer and flushes it clean. When this is accomplished stops *b* and *f* are opened and *a*, *d*, and *e* are closed, thus by-passing the mixer and sending the water directly to the pump. When all the wash water is in, the casing is set firmly on the bottom of the hole. Under normal conditions this will stall the pumps. By opening the relief valve *b* (see Pl. VII and *c*, Pl. VIII) at the casing head all cement that may have remained either in the tubing or in the casing above the bottom of the tubing will be washed out by merely keeping the pump going.

After getting circulation at the beginning of the job, it is unnecessary to stop the pump or the movement of cement or circulating



DIFFERENT STAGES OF CEMENTING OIL AND GAS WELLS BY TUBING METHOD.



EMENTING OUTFIT.

fluids until the job is entirely completed and the casing is safely landed. If the operator does not wish to have to drill any cement out of the casing the tubing may be lowered to within a few inches or a foot of the bottom and all the remaining cement flushed out by water being pumped into the tubing. Notwithstanding the difference in the specific gravities of cement and water, it is a remarkable fact that a large slug of liquid cement with water both above and below it may be pumped down a string of 3-inch tubing, and if desired can be pumped again to the surface through the space between the tubing and the casing without excessive intermingling between the cement and the water.

It must be borne in mind that no barrier, not even a cement sack, is used between the cement and the water in this process. A striking instance of pumping cement back to the surface between the tubing and the casing occurred at one of the Pacific Midway Oil Co.'s wells in the Sunset oil field where liquid cement was pumped into a 10-inch hole, about 1,600 feet deep, through tubing. It was desirable in this particular well to pump in all the cement that the hole would take, so 18 tons (360 sacks) was mixed and pumped in. Of this amount 2 or 3 tons was washed back to the surface. When the cement came to the surface it was in such usable condition that a tank was placed to catch it. The tank full of liquid cement was hauled to a garage on the property where the cement was mixed with sand and used for laying a concrete floor in the building. This condition of the cement after being returned to the surface is the rule, not the exception.

Of course, if the tubing happened to extend only a few inches into the liquid cement at the bottom of the hole, only those few inches of cement would be washed back, and the cement might then be so diluted on reaching the surface that it would not set; but where, say, a ton or more of cement is involved, it may be washed back to the surface in fair condition. In most instances of this kind there is no useful purposes to which the return cement may be put, so it is usually wasted. Fortunately it is usually possible to estimate rather closely the requirements of the particular job.

The reader may wonder why so much discussion should be devoted to the setting of the returned cement when the chief concern is how it sets underground. One important reason is that if the cement sets after being returned to the surface, any failure to set underground can not logically be attributed to the character of the cement nor to the method of mixing and placing it. Another reason is fully discussed under "Casing System of Cementing without Plugs," on pages 50 to 53.

SPECIAL METHOD OF MIXING CEMENT.

The Shell Co. of California uses an ordinary concrete mixer fastened in the discharging position. The mixer is set to dump into a long mixing box about 2 feet square in cross section, and approximately 20 feet long (Pl. IX, A). A hose discharges water into the mixer continually as the cement is dumped in. Men with mortar hoes finish mixing the liquid cement as it travels from the concrete mixer at one end of the long box to the 6-inch suction at the other. From the box the cement is taken by the pumps and delivered to the well.

The two pumps, shown in the left foreground of Plate IX, A, are mounted on a low truck. One pump is for low pressure and the other for high pressure, and they are 10 by 6 by 12 inches, and 10 by 3 by 12 inches in size, respectively. The suction manifold is so connected that it will take either cement from the long box or water from a 3-inch connection into the same manifold. The discharge manifold and the steam connection to these pumps are so arranged that the operator may change from the low to the high pressure pump, or vice versa, without stopping the flow of liquid through the tubing.

Some companies have a hose connected to the pump-discharge manifold so that the cement may be picked up by the suction and circulated through the pump back into a mixing box, thus making the pump serve also as mixer. This method increases the wear and tear on the pump and necessitates mixing all the cement before putting any of it into the well.

USE OF ONE-PLUG METHOD WITH TUBING.

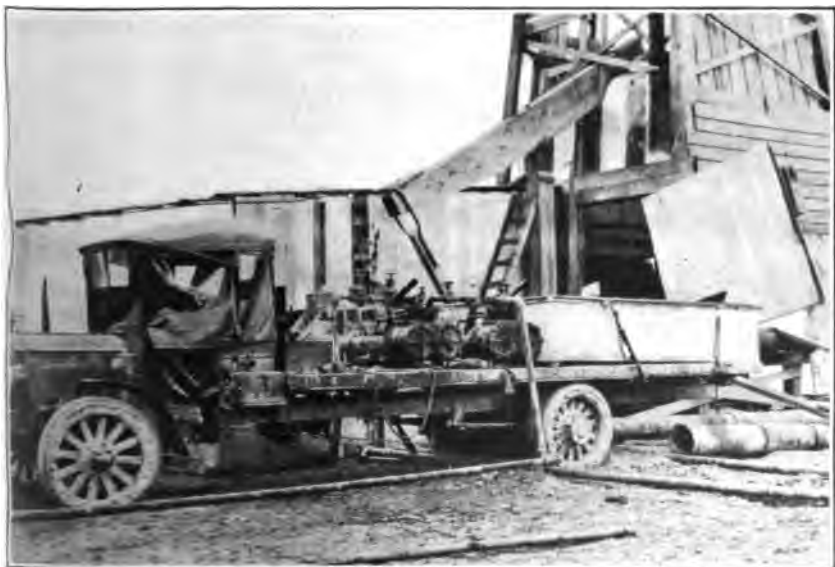
A variation of the tubing method not extensively used at present consists in placing a swaged nipple on the bottom of the tubing and using a wooden bullet-shaped plug, having a disk of leather or rubber belting nailed to the flat end. This plug, point down, is inserted into the tubing on top of the column of cement, and is pumped down with water in the usual way. The plug will stop when it reaches the swage nipple, thus stalling the pumps and indicating the end point and affording a check on the computations. This check is the one advantage over the common method as described above. The disadvantages are as follows:

1. Cement often adheres to the sides of the tubing and subsequently settles on top of the plug, or else the plug works down into the cement leaving as much as 6 or 7 joints of the tubing filled with cement. The tubing thus filled either has to be junked or else the cement must be drilled out at considerable expense.



A. SHELL CEMENTING OUTFIT AT WORK.

Photo by C. W. McAlester, Coalinga, Cal.



B. PERKINS CEMENTING OUTFIT WITH STEAM AND WATER CONNECTIONS MADE.

2. It is impossible to wash cement out of the bottom of the tubing or casing after the latter has been set.
3. If circulation is interrupted, all cement not already back of the casing is left inside of it to be drilled out.

USE OF THE BAKER CEMENT CONTAINER.

The "Baker cement container"^a is a device to be used under certain conditions when cementing with tubing. The container is primarily designed for use when circulation may be obtained, but when it is impossible to get a tight seat for the casing on the bottom of the hole. The condition may be caused by lost tools which have been sidetracked and subsequently fallen in against the casing, or the casing may have become "collar bound" so it may be moved 5 or 10 feet, but not enough to clear the couplings. If the cementing job be attempted under such conditions by the ordinary tubing method, or any of the other methods, an opportunity is afforded for the cement to run back into the hole from behind the casing when the job is allowed to stand.

The container is built of cast iron and is attached to the bottom of the tubing by a left-hand nipple *a*, Plate V, *D* (p. 36). This nipple connects with the lower cone-shaped part of the container *b*. When the container has been lowered to the shoe joint, or as near the bottom of the casing as may be desirable, pulling the container up a few inches or a foot is sufficient to cause the slips *c* to wedge against the inside of the casing, holding the upper section of the plug firmly in the casing. Thus the rubber *d* is spread by the cone-shaped base *f*, making a tight seal between the plug and the casing. When the cement is pumped down the tubing it will readily pass the valve *e* which is seated by a spiral spring. The cement can not, however, pass back through this valve or around the container to get above it, and must therefore pass around the casing shoe and follow the course of circulation.

When all the cement has been pumped in, the tubing is disconnected from the plug by unscrewing the left-hand nipple *a*. Any residual cement in the tubing may be pumped out and to the surface, just as in the ordinary tubing method. The container is prevented from slipping down the casing after being disconnected from the tubing only by the friction hold of the slips and the pressure of the cement on the bottom of the container. However, if the cement has not pressure enough to hold the container in place, not much is likely to run back into the hole. As the container is built of light cast iron it is easily drilled up after the cement has set.

^a Baker, R. C., Cement container: U. S. patent 1085674, Aug. 13, 1912.

ADVANTAGES OF TUBING METHOD.

The advantages of the tubing method may be summarized follows:

1. The method requires less time after the initial wetting of the cement to completion of the job than any other method yet devised.
2. The operator can leave any desired quantity of cement inside the casing.
3. The storage space required for wash water is less than that required for the casing method of cementing.
4. When a standard-tool hole is to be cemented by the tubing method the volume of water unavoidably circulated around the casing ahead of the cement is only the contents of the string of tubing. This is a considerable advantage if the formation back of the pipe has a tendency to cave.

DISADVANTAGES OF TUBING METHOD.

Disadvantages of the tubing method may be enumerated as follows:

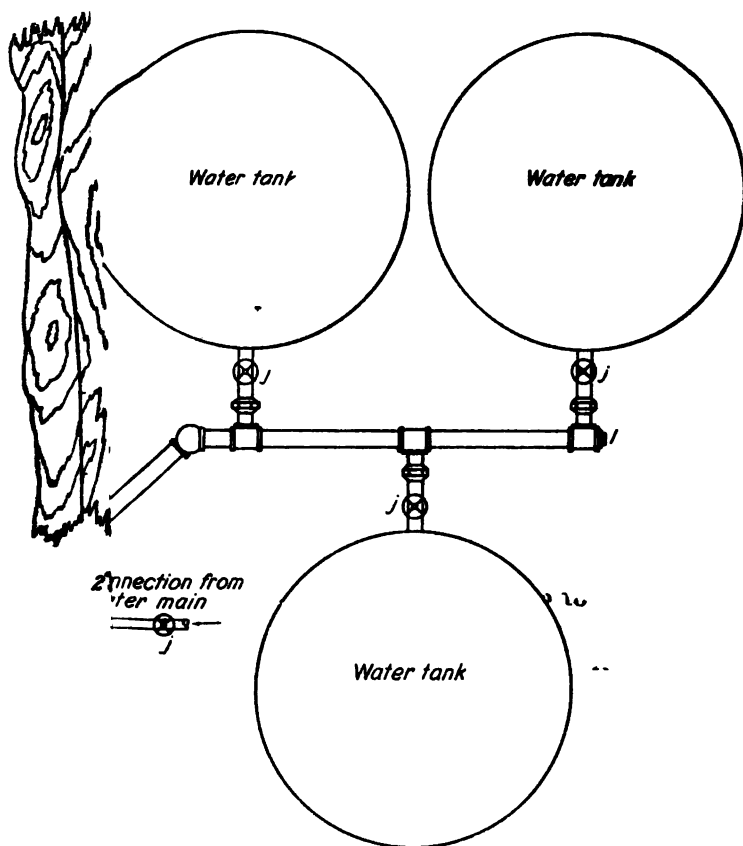
1. Time is required to run in a string of tubing. This usually has to be laid down after the job in single joints and rolled away from the rig to permit unloading of pipe for the oil string, as well as other equipment.

2. Although the tubing method is quicker than the casing method after the cement is wet the aggregate time required to do the job is considerably greater on account of handling the tubing. For this reason some form of casing method is very popular among operators for mud-flush holes—particularly for holes drilled with rotary tools. This is because of a desire to reduce the delay to a minimum, especially in a rotary hole, as the wall of an uncased hole in California will not stand long. Also in a tubing job either the drill pipe must be laid in single joints as it is pulled out and the tubing must be stood up or else casing will have to be done with a string of tubing as well as a string of drill pipe standing in the derrick, impeding the work of casing the hole.

CASING METHOD OF CEMENTING.

In cementing casing by the casing method the liquid cement is pumped down inside the casing itself without the use of tubing bailers, or other containers of any kind. There are two general methods of performing this operation, as follows:

1. A plug or barrier of suitable material and construction is used below and another above the column of cement, separating it from the other fluids in the hole during its passage down the casing.
2. No plug or barrier of any kind is used, either below or above the column of cement during its passage.



USE OF TWO PLUGS (PERKINS PROCESS).

The former method is commonly known in California as the "Perkins process,"* the main features of which are as follows:

1. The circulation is established downward through the casing and up outside it.
2. Plug No. 1 is inserted at the top of the casing. The fittings are then replaced and the cement pumped in on top of this plug.
3. When the desired amount of cement has been pumped into the casing the pumps are shut down and plug No. 2 is inserted on top of the cement. The fittings are again replaced. Water is then pumped in on top of plug No. 2, forcing it down the hole. Thus the slug of cement travels down inside the casing, pushing plug No. 1 and the water or drilling mud ahead of it and having a column of water behind it. (See Pl. XIII, p. 48.) The plugs not only keep the cement from intermingling with the other fluids in the hole, but play a most important part in the mechanical operation of the process. Each outfit consists of a 3-ton motor truck on which the pumps are mounted; two pumps, low and high pressure, 10 by 4½ by 10 inches and 10 by 3½ by 10 inches; two or more galvanized-iron boxes for mixing the cement.

MIXING AND SUCTION BOXES.

Unless more than 10 tons of cement, 200 sacks, is to be used, the two boxes regularly carried as part of the equipment will have sufficient capacity. The larger of these boxes is 10 by 6 feet by 2 feet deep inside. The smaller box is of the same depth, but 4 inches shorter in each of the other dimensions. During transportation one box may be placed inside the other. Each box has a 2-inch angle iron around the rim to stiffen and reinforce it.

Plate IX, *B* (p. 40) shows an outfit backed in beside a rig and with the steam end of the pumps connected. The mixing boxes were still chained on the rear of the truck when the photograph was taken. Each box has one-half of a 4-inch flange union riveted to the bottom as a reinforcement for the discharge opening. One of these outlets is shown in Plate IX, *B*, protruding from the bottom of the mixing box almost directly above the rear wheel of the truck. These outlets must be placed one in the upper left-hand corner of the first box and the other in the upper right-hand corner of the second box as one looks into the boxes. Such an arrangement permits the boxes to be placed as shown in Plate X, one on either side of the suction box and with the discharge openings over it. These discharge openings are closed by wooden stoppers while the cement is

* Perkins, A. A., and Double, Edward, Method of cementing oil wells, U. S. patent 1011484, Dec. 12, 1911.

being mixed. The stoppers may be pulled out part or all the way, thus regulating the flow of cement into the suction box.

The suction box is of galvanized iron reinforced around the rim with 2-inch angle iron. The box is 2 feet deep and 2 by 3 feet at the top. The sides slope to a bottom 1 foot 10 inches by 2 feet 10 inches, thus having a batter of one-half inch to the foot. A pit is dug beside the truck for the suction box, which is set with its rim flush to the ground surface. By this arrangement the mixing boxes may rest flat on the ground and yet have their discharge openings set over the edge of the suction box, thus saving the labor and expense of elevating the mixing boxes. A 3-inch suction pipe from the high-pressure pump and a 4-inch pipe from the low-pressure pump are dropped into the suction box. (See Pl. XI, A.) This illustration also shows the 1-inch mixing hose in the central foreground and the corners of the mixing boxes as they are set. When the photograph was taken the cement had been mixed and the wash water was being pumped into the casing. The exhaust steam from the pump in the background may be noted.

PLUGS.

The two plugs, although differing in detail, have many points of construction in common. The bodies of both plugs, or barriers, as they are termed in the patent specifications, are commonly made of California redwood, though any good clear soft wood, such as white pine or sugar pine, would have ample strength. As these plugs must be drilled up after the cement has set, the softer the wood can be, and yet do its work, the better it is for the purpose. This requirement is kept in mind in making No. 2 plugs, which are turned down between the two ends to remove superfluous stock. The bodies are fitted with wooden stud bolts 1 inch in diameter with 4 threads per inch in the plugs for $4\frac{1}{2}$ -inch casing, and $1\frac{1}{2}$ inches with 3 threads per inch for sizes used in $6\frac{1}{4}$ -inch and larger casings. The stud bolts are in one or both ends of the plug according to its design and are held in place by transverse wooden pins, the white ends of which show plainly in the photographs reproduced as Plate XII. The flat washers or disks are made of ordinary rubber belting, such as is used for the standard rig.

Plug No. 1 is made in two designs. The first type is the tall, bottle-necked plug shown to the left of each group of plugs in Plate XII, A. It has a rubber washer at the top and at the bottom. The bottle neck is immediately under the upper washer, which is held in position by a single wooden disk on top of it. These plugs are 3 feet long over all. This length is approximately constant for use in all sizes of casing. This type is used for all jobs except where a "Graham" cast-iron guide (4, Pl. I, A, p. 22) or similar device is

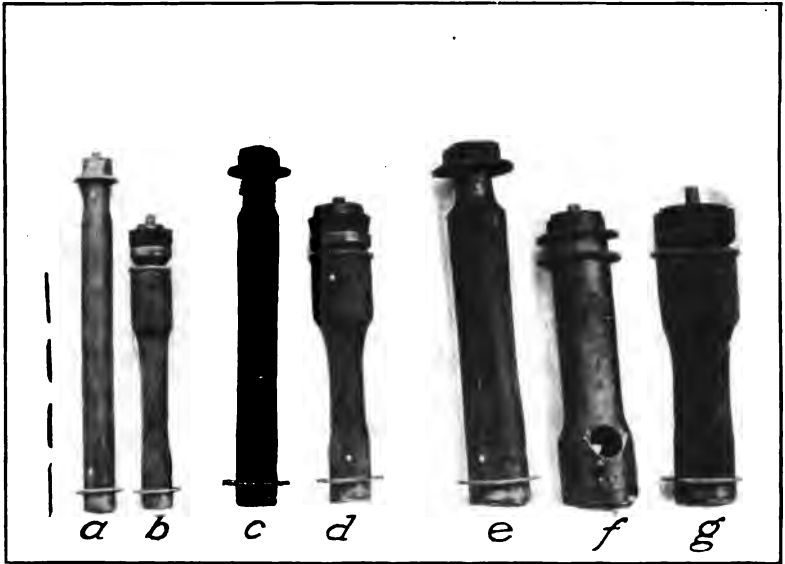


A. SUCTION AND DISCHARGE END OF PERKINS CEMENTING OUTFIT.

Note heavy (1,500-pound) fitting on end of discharge line, also 1-inch mixing hose connected into the discharge of the low-pressure pump. Two-inch line to well is shown at *a*.

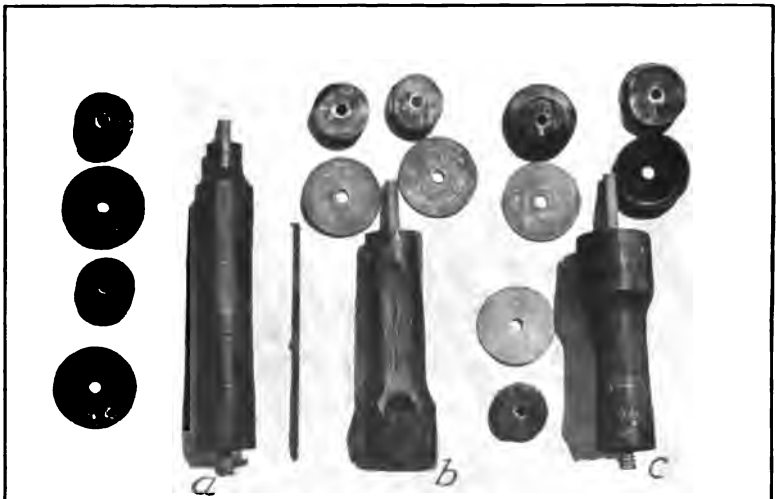


B. STEAM END OF PERKINS CEMENTING OUTFIT.



A. PERKINS CEMENTING PLUGS.

a, b, Plugs for use with $4\frac{1}{2}$ -inch, 15-pound casing; *c, d*, plugs for $6\frac{1}{2}$ -inch, 28-pound casing; *e, f, g*, plugs for $8\frac{1}{2}$ -inch, 36-pound casing.



B. PERKINS CEMENT PLUGS DISMANTLED.

All three plugs are for use in $8\frac{1}{2}$ -inch, 36-pound casing. Plug *a* is for use when no float plug is used on casing shoe (see *a* and *b* in Plate XII, *A*). Plug *b* is for use when float plug is used (see Nos. 3 and 4 in Plate I, *A*, also Plate XII). Plug *c* is the upper or second plug and is of same design for all uses, varying only in dimensions to fit size of casing employed.

used. Such a guide, or float plug, as it is termed in the catalogue, is commonly used for setting casing in a rotary hole. Plate XIII (p. 48) shows a shoe guide on the casing represented in the different views and illustrates clearly the necessity of altering the design of the first plug for such jobs. As the wooden plug can not pass out through the shoe guide, it is necessary to provide some means for the cement to by-pass and get out around or through the plug in order to be ejected from the casing. Plates XII and XIII show one method of meeting this need. Two washers are put near together at the top of this type of plug and the base is enlarged to prevent any chance of its passing through the shoe guide. No washers are used on the lower end. In order to permit the cement to pass out of the casing after the shoe guide has arrested the plug, a 3-inch hole is bored vertically into the bottom and joins others from either side of the plug, thus forming a Y. The pressure of cement on top of the plug bends down the rubber disks, as shown in *C*, Plate XIII, allowing the cement to pass through the Y and out the bottom of the plug.

Plug No. 2 is of the same construction for all kinds of jobs, differing only in diameter, which is such as may be required to fit varying sizes of casings. The essential difference between it and the No. 1 plugs is in the leather cup placed on the top. This cup is much like the leather cups commonly used in oil-well pumps, but is of larger diameter. The object of this leather is to effectively prevent liquid from above the plug passing around it at any time during the job, and without regard as to whether the progress of the plug has been arrested or not.

For plugs to fit 6½-inch casing and smaller sizes, the rubber washers have a diameter one-eighth of an inch greater than the internal diameter of the corresponding size of casing. For 8½-inch casing and sizes larger, each washer has a diameter one-fourth inch greater than that of the casing.

The various wooden disks are turned out of Oregon pine with the grain running across the disk, at right angles to the grain in the body of the plug when set up. The disks also have flattened places or wrench squares on them. Owing to their shape, these disks are more easily broken or split than the redwood body of the plug, and hence are made of harder wood. Oregon pine, which is much like the ordinary Eastern yellow pine in physical characteristics, is generally used for the disks.

WATER METER.

The water meter is provided to measure the volume of wash water as it is pumped in on top of the second plug. Water should pass the meter at sufficient rate to complete the cementing job in an hour. Of course, many successful jobs take a greater length of time than this,

but one hour seems about the maximum limit for desirable conditions. As the pumps are usually slowed down toward the end of the job, owing to the increased pressure, the meter should have a capacity of approximately 50 per cent over the average rate of supply for the entire job in order to pass a large volume of water during the earlier stages of operation.

Unless a most reliable water supply in adequate quantities is at hand, local storage must be provided, not only equal to the volume of the casing that is to be cemented, but a little in excess of this volume. It usually happens that such local storage has only a small static head above the meter and suction box. Under these conditions a small duplex pump about 4½ by 3 by 4 inches, set up to force the water to the meter, will overcome the difficulty and accelerate the entire job.

MIXING HOSE AND NOZZLE.

The hose is a 1-inch high-pressure line connected to a fitting on the low-pressure discharges (see Pl. X, p. 42, and Pl. XI, A, p. 43). This pump will deliver at about 400 pounds pressure per square inch, which is far more than is required for mixing purposes. The nozzle consists of a piece of ½-inch pipe, 3 or 4 feet long and securely clamped into the end of the hose.

OPERATION OF TWO-PLUG PROCESS.

All water reaching the cementing outfit must run through the meter and be handled by the pumps. (See Pl. X, p. 42.) Circulation should be established either with the mud pumps at the well or with the pumps of the cementing outfit. After the fluid or water is circulating, the casing should be set on bottom a few times to see whether the pumps will be stalled by so doing. If they are, no cement is apt to run back into the casing after it is permanently landed. As a number of hours or even days may be consumed in getting good circulation, the cement must be protected from moisture and should not be dumped until everything is in readiness for it. It should then be divided between the mixing boxes and piled in the ends opposite the discharge openings. By running water into the suction box through the meter it may be pumped through the 1-inch hose and the mixing nozzle under a strong pressure. While this is being done the valves *c* and *d* (Pl. X, p. 42) of the discharge line into the well should be closed. By playing this powerful jet back and forth across the pile so as to slice it in thin layers, the cement is mixed more easily and more thoroughly than with hoes alone. In addition to the mixing nozzle there should be 4 to 6 men with hoes at each mixing box.

While the cement is being mixed, part of the crew is engaged in removing the steel bushing from the top of the casing and inserting

plug No. 1. In reference to the water-supply connections at *m* (Pl. X) it is important that the high-pressure line have a straight connection into the low-pressure line from the storage tanks to the meter. Numerous set-ups have been observed in which this feature was overlooked and the high-pressure line connected at 90° into the low-pressure manifold. The result of such a connection frequently is that the high-pressure stream divides on entering the manifold, part going to the meter and part backing up into storage tanks, thus making it impossible to use water from the high-pressure line and the storage tanks simultaneously.

There is a top and bottom to each plug, and if either is put in wrong end up serious difficulty is likely to follow. After the first plug has been inserted and the casing connections replaced, everything is in readiness to receive the cement.

The pump man, after opening valves *e* and *c* (Pl. X) starts the low-pressure pump while one of the mixing gang pulls the stopper from the cement-box outlet at *k*, and lets the liquid cement run into the suction box as fast as the pump removes it. The mixing boxes are emptied in this way one after the other. Throughout this operation the stopcock under the pressure gage connection should be kept closed to prevent the gage from becoming fouled with cement. When the cement has all been pumped into the well, the pumps are run a few strokes on water to clear them and the discharge line of cement, and are then shut down. The fittings are removed from the casing for the insertion of plug No. 2. While this is being accomplished the meter must be carefully read and the reading recorded. When the connections are again made at the well, the pumps are started, water being run through the meter to the suction box (Pl. X). It is well to measure the volume of the liquid cement in the boxes before pumping it into the well. A ton of cement when mixed and wet occupies about 23 to 30 cubic feet. By computing the volume of the casing (see Table 1, p. 20), it is impossible to predict with a fair degree of accuracy the meter readings at which the first and second plugs, respectively, should strike bottom. Of course, if everything goes all right the pumps will stall when the second plug reaches the first (see *D*, Pl. XIII), and there would be no need of the meter were it not for the absolute necessity in some jobs of knowing in advance when the first plug is due to reach the bottom of the casing.

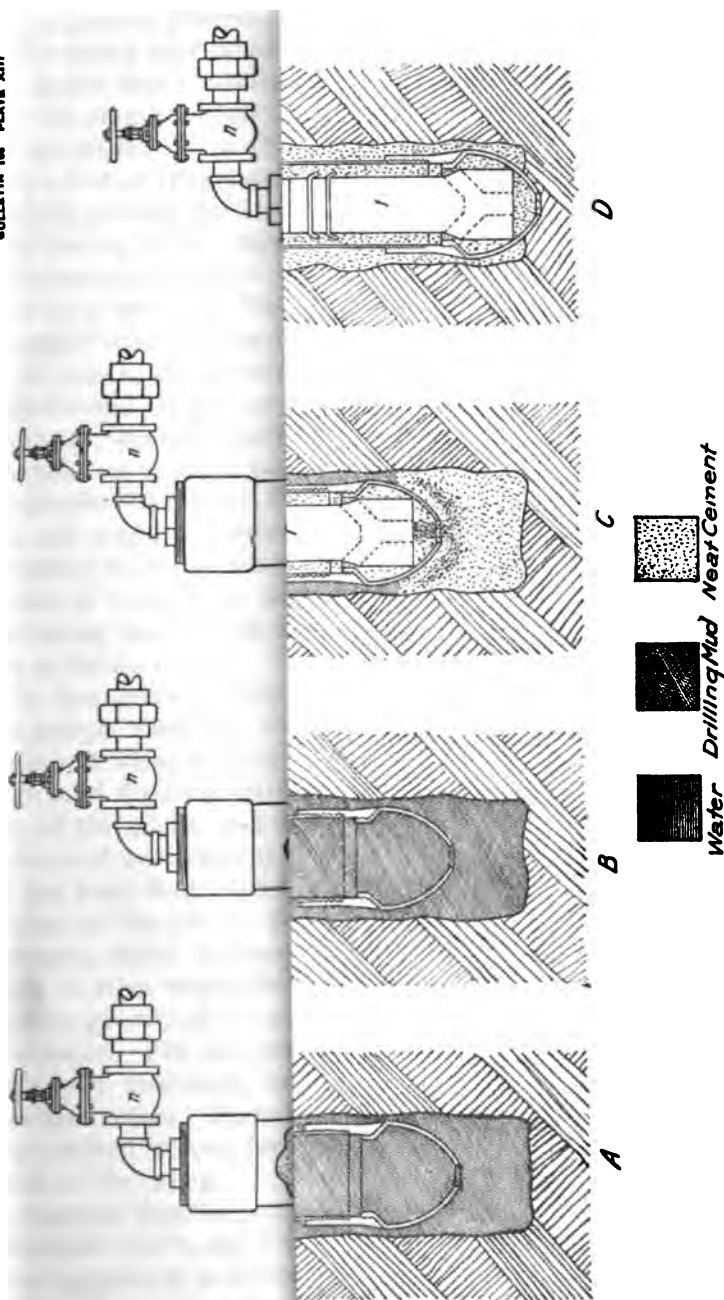
Unfortunately this system has one point in common with every other oil-well device yet devised in that it will sometimes not work out as expected. When trouble occurs it is usually due to a cave-in shutting off the circulation, or a split joint in the casing allowing the cement to pass out the side of the pipe, or to some such cause, for which the cementing process is not to blame.

Normally the weight of the cement as it descends in the casing is sufficient to cause a pressure less than atmospheric on the discharge connections from the pumps. The immediate result of this reduced pressure is a speeding up of the pumps, the action being really that of a siphon. This siphoning effect gradually diminishes until the first plug has reached the shoe guide (*C*, Pl. XIII), or the bottom of the hole, or until the various liquids inside and outside of the casing have established equilibrium. After equilibrium has been attained the pressure will begin to build up to perhaps 200 to 250 pounds per square inch by the time the second plug has encountered the first (see *D*, Pl. XIII). When this occurs, there is usually a perceptible jump to 300 or 400 pounds per square inch. The valve *n* (Pls. X and XIII) is closed and the casing is set on the bottom. In every job observed the entire computed amount of water was used, and usually an excess of 10 to 30 cubic feet was needed. This excess represents 0.75 to 3 per cent of the total wash water used.

So much for a well with which everything goes according to schedule. Sometimes an operator is forced to take a chance on trying to cement a well when conditions are not favorable. Suppose that everything has started all right and the pumps have been forcing the cement down the hole for one-half hour and the pressure builds up and reaches 300 or 400 pounds. The question immediately arises, Are the plugs down, or has the hole caved sufficiently to retard circulation? The meter, of course, gives the answer. If the computed volume of water has been run through the meter, it is time to set the casing; if not, the high-pressure pump must be used.

As it is impossible to foretell whether the high-pressure pump will be needed, all fittings on the discharge line must be designed to withstand the high pressure. In this connection 250-pound fittings are not to be considered high-pressure fittings, merely because they will probably withstand a pressure of 800 or 900 pounds before bursting. Only fittings rated by the manufacturer to work at as high a pressure as the maximum delivery of the high-pressure pump should be used. An operator who does not provide fittings of such a character is guilty of criminal negligence, and the mere fact that he may have used low-pressure fittings a thousand times before is no mitigation for job 1001, on which a fitting blows up and kills some one. This paragraph applies to other phases of the oil business as well as to cementing.

Ordinarily from the computations one can tell about when the first plug should reach its destination and can be watching the pump carefully at this stage. A slight momentary tendency to slow down can usually be noticed, followed by a couple of quick strokes of the pump. Resting one's hand on the pump will usually facilitate in detecting such a vibration. Although it is not absolutely necessary



CROSS SECTION SHOWING DIFFERENT STAGES OF THE "PERKINS PROCESS" FOR CEMENTING OIL AND GAS WELLS.

to know when the first plug reaches bottom, the knowledge is a check on the general progress of the work, and is well worth observing.

The casing may be moved up and down as much and as often as the driller deems advisable while the cement is descending. When the first plug is within 100 or 150 cubic feet from the shoe, as shown by the meter, the driller should lower the casing until the shoe is only a foot or 18 inches off bottom. This will not hinder circulation, but will prevent the first plug from going entirely out of the casing, thus leaving it as a firm stop on which the second plug may land. This procedure should be followed even when a shoe guide is used, such as is shown in Plate XIII, as such a guide may be broken or pulled off the casing and should not be trusted alone to stop the plugs.

As soon as the second plug has stopped, the valve *n* (Pl. XIII) is closed and the casing lowered to bottom, as described. Ordinarily, this valve should be left closed for at least 24 hours after the casing has been set in order to leave a column of water on top of the plugs to prevent the cement from running back into the casing if the shoe has not made a water-tight seat on the formation. It is hardly necessary to say concerning this cementing process, as is true with others, if there is an accident which causes the cement to lodge in the casing the cement should be cleaned out immediately before it has a chance to set.

In this process there is usually some difference in the action of the pumps when the well has been drilled with ordinary standard tools and when it is in a rotary or mud-flush hole. In a hole filled with mud fluid the fluid is forced out of the casing by the water on top of the plugs, and there comes a time when the weight of the column of mud, cement, and water inside the casing is less than that of the mud fluid outside of the casing. From then on to the completion of the job the pumps must compensate for this difference of pressure, which increases steadily until the second plug reaches the first; in other words, the pumps must compensate for the difference in specific gravity of the cement and the mud as compared with that of the water. For this reason in a hole filled with mud fluid the pressure will frequently commence to build up before the first plug reaches bottom. However, the increase is more rapid after the plug has reached bottom, for the cement as well as the mud is being raised back of the casing.

Suppose that the pumps do not steadily build up the pressure and the meter shows, say, 75 per cent of the water already in. Whenever this happens it is advisable to get a handful of the returns and see if they have any odor of fresh cement about them. One can often detect the odor of cement in the muddy returns long before he can see the cement. Sometimes a hole in the casing or a split joint will

allow the cement to pass into the returns without going around the shoe. Every now and then, say two or three times while the cement is being pumped down, the driller can lower the casing to bottom. If this procedure did not shut off circulation when first tried it will not do so at a later stage of operations, but, on the other hand, if it did shut off circulation before the job was started and will not do so later, the chances are that the casing has parted, probably well down in the hole; otherwise the driller would have noticed the jump when parting occurred. It is entirely possible in a shallow hole with a large quantity of cement that the latter may circulate clear to the surface in a normal and successful job. Ordinarily such excess of cement will not be used in a shallow hole. If the foreman in charge becomes convinced that something has gone wrong and that the best policy is to pull the casing, mud fluid, where available, should be started in immediately on top of the water. The fluid will tend to keep the walls of the hole from caving if the well is in a loose formation, and also will assist in flushing the cement out of the hole so that it will not set and have to be drilled out.

In any of the pumping methods it is customary to connect the discharge line from the pumps to the casing by a long swing or other flexible connection, thus making it possible to raise and lower the casing as the job progresses.

CASING METHOD WITHOUT PLUGS OR BARRIERS.

In the foregoing pages three excellent cementing outfits for mixing and pumping cement into wells have been described. As any one of these can be used equally well on any pumping job, the only remaining step to consider is what happens after the cement leaves the pumps.

If the Scott outfit were used without tubing, or the Perkins without plugs, one would have the casing method without barriers. In other words, the liquid cement may be, and, in fact, sometimes is, pumped into the casing on top of the liquid in the hole—mud fluid or water—and is forced down the hole either by mud fluid or water above it. This procedure is like increasing the diameter of the tubing used in a tubing job till it becomes too large to go inside the casing so that the casing itself must be used instead. The wash water may be either gaged in tanks or run through a meter.

Two important questions arise in regard to this method, as follows:

1. Will there not come a time as the diameter of the tubing is increased when the cement, being heavier than the mud fluid or the water, will work down into the lighter fluid below and become so diluted that it will not set?

2. How will an operator determine the end point and know when to land his casing?

To answer the first question it is well to define limits and to consider casings between the sizes of 3 inches and 10 inches. Strings of 12½-inch casing are sometimes cemented for certain drilling advantages gained thereby, but rarely is a string of casing larger than 10 inches in diameter cemented by a pumping method. It is fair to assume that if the cement does not mingle with the other fluid in the hole under conditions favorable to intermingling it will not do so under less favorable conditions.

Citation may be made of two wells having unfavorable conditions under which the cement set. In both these wells the peculiar conditions of the job made it impossible to foretell how much cement would be required; hence a considerable excess had to be provided to insure a sufficient supply. Both illustrations are from the wide experience of Mr. F. W. Scott, of Taft, Cal., who was in personal charge of the work. One well belonged to the Pacific Midway Oil Co., near Maricopa, Cal. (See p. 39.)

The other instance involved a bottom-hole job in which it was important that the cement should fill 35 feet in the bottom of the hole, but no more. The hole was 4,135 feet deep in the east side of the Coalinga field. Forty-two sacks of cement were mixed, 40 pounds of water to 100 pounds of cement, and pumped to the bottom through 2-inch tubing. When the cement was all in, the tubing was pulled up 35 feet off bottom and the pumps started forcing water down the tubing until the cement above this point was all washed back to the surface between the 2-inch tubing and the 6-inch casing. Mr. Scott was kind enough to catch a sample of the return cement in a quart preserve jar and express it to the writer after the cement had set. Ten days after the sample had been caught, the writer broke the glass jar away from the cement and found it set hard. There had been no shrinking of the cement cake way from the wall of the jar, as was demonstrated by the highly glazed surface of the cake, and by the impress of the label pressed in the glass. When the jar was first opened the top of the cement was sufficiently soft to be easily scraped with a knife, but the lower part was hard. Though this slug of cement gave the appearance of having suffered considerable dilution when in the liquid condition it had set hard enough for ordinary well purposes.

The whole force of these instances in connection with cementing casing without the use of plugs or barriers is that they represent conditions where the cement was far more subject to dilution than in ordinary cementing of casing without plugs. When cement is pumped down tubing and forced back to the surface between the tubing and the casing against the force of gravity with all the drag

of friction against casing and tubing, augmented by the rattle action of the couplings on the tubing, the agitation is considerable. The conclusion seems justified that when cement is pumped down inside casing 10-inches in diameter or smaller, without the use of plugs or barriers, the cement mixture and the other fluids in the hole tend to intermingle, though as a rule this intermingling is not serious, particularly when the cement has originally been mixed with only a small proportion of water.

The second question as to how to determine the time to land the casing brings out a serious weakness in the method. As either a meter or a gage tank may be used, the relative accuracy of gaging or metering the wash water is not the question at issue. Considering that such gaging is usually done in 50-barrel or 100-barrel tanks that have been dumped off the trucks numerous times, and had their sides dented, to be afterwards driven out to restore more or less the original shape of the tank, the writer thinks the relative accuracy of the two systems is about the same. The meter is more easily read than the low gage wet-line mark on a notched stick, particularly if the cementing is done at night. The use of the meter also reduces the chances of error by eliminating one set of computations. All things considered, assuming no errors in computations, the general average of 10 cubic feet of allowable variation between the volume of measured water and the actual capacity is a 2,500-foot hole of 10-inch casing is a close limit. This is an allowable error of about 0.7 per cent, and is here applied alike to both methods of measurement. Ten cubic feet in 10-inch casing occupies about 18 linear feet; that is, an operator's computations should allow for leaving at least 18 feet of cement in the casing to obviate the possibility of washing the cement away from the shoe. He may find either no cement or about 36 feet of it in the casing, according to whether the allowable error has been plus or minus. Many operators do not object to this feature and sometimes require that 10 to 20 feet of cement be left in the hole.

There are two causes for such a requirement—first, the fear that too much water will pump the cement not only to the bottom but up outside the casing and away from the shoe joint to a point where it is not needed. An excess of water will undoubtedly produce such a result. The second cause is the claim that the latter part of a batch of cement is "mushy" and had better be cleaned out of the hole later than to be put behind the casing and not do its work. This contention is supported by the results at numerous wells, where the cement left inside the casing had a few feet (at some wells 20 feet) of mushy, chalky deposit on top, the underlying cement being set hard. So firmly is this conviction held by some operators that even when using the two-plug method they drop a timber 4 by 4 inches by 20

feet long into the casing between the plugs, which will stop the second plug 20 feet above the first, thus leaving this amount of cement in the bottom of the casing. This practice does not refer to instances where a timber, say 10 feet long, is used to obviate the danger of both plugs escaping from the casing.

It seems probable that the "mushy" cement constitutes that which has adhered to the inside of the casing and gradually settled to bottom much diluted, or is composed of good cement left inside the casing and prevented from setting by mechanical agitation, such as the working of gas or some other cause.

On the other hand, there is a serious disadvantage to drilling hard cement out of a water string. Any pounding or grinding inside the casing has a tendency to crack and loosen the cement mass formed around the exterior of the pipe. If some form of casing method is to be used, the writer would prefer the two-plug system without the use of a timber between the plugs, unless, owing to certain peculiar conditions of the hole, such a timber should be necessary to prevent the second plug as well as the first from escaping.

ROTATION OF CASING DURING CEMENTING.

Some operators have devoted considerable attention to the possibility of cement channeling around the casing instead of forming a solid sleeve between the casing and the wall of the hole. The results of such an occurrence and the means for preventing it by underreaming when cable tools are in use are discussed in subsequent pages. Underreaming is not applicable to water strings set in a rotary-drilled hole.

Some three or four years ago an effort was made by the Standard Oil Co., operating in the Kern River field, to overcome the channeling difficulty and to insure a more uniform distribution of cement around the casing by rotating the casing while cementing was in progress. The rotation was accomplished by the use of tongs. The practice was discontinued.

Recently, in the spring of 1917, Mr. Richard Sperry, of the General Petroleum Corporation, developed a system for rotating water strings while cementing, and he has used it extensively on the Belridge property of the company. Water strings on this property are cemented at approximately 600 feet below the surface in rotary holes. After the hole has been drilled to the required depth, the casing is inserted and circulation is obtained with the pumps in the usual manner. The casing is set on a spider which rests on the rotary table, as shown in Plate XIV, A. The spider is prevented from slipping by steel pins set in the sockets in the top of the rotary table designed to take the adjusting screw posts of the grip rings.

The casing is handled with the swivel. The table is rotated continuously at about 16 revolutions per minute while the cement is being pumped down. As the "Perkins process" is used, some quick and convenient method must be provided for the insertion of the plugs into the casing. The heavy steel flanges at *a* (Pl. XIV, A) are for this purpose. These flanges are held together by eight wing bolts attached to the lower flange.

On the face of the upper flange is a concentric groove to take hydraulic packing which seats on the bottom flange and prevents leakage. Mechanically this system as a rule operates with entire satisfaction, though an occasional crooked hole may preclude the possibility of rotating the casing. Just to what degree the procedure will increase the percentage of successful jobs is as yet unknown, as few holes cemented in this way have been tested to date.

All threaded connections between the rotary table and the swivel should be left-hand in order to prevent their backing off. Although the proper number and size of the bolts in the flange depends on the weight of the casing, the friction of the formation, and other such considerations, it must be kept in mind that such a fitting is not designed for pulling a loggy string of pipe. When such work is to be done, elevators of a suitable kind must be used.

QUANTITIES OF CEMENT USED.

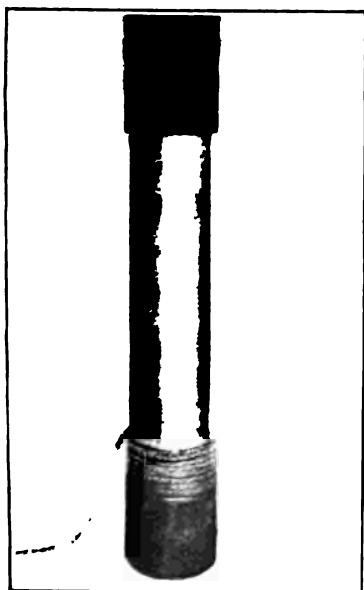
To attempt an estimate of the amount of cement required, even in a general way, is much like trying to estimate the number of bricks in an ordinary house without knowing the thickness of the walls, or the length, breadth, or height of the house. There are obviously many variable factors, such as the volume of the annular space between the casing and the wall of the hole, assuming that the latter is a true cylinder concentrically surrounding the casing; or any caving that may have taken place during drilling, as well as fissures, crevices, or pervious strata into which the liquid cement may percolate; also, in some wells it may be desirable to force the cement a long way up behind the casing, whereas in others it may not.

It will thus be seen that the man in charge of the particular operation must depend chiefly on his own judgment, estimates, and computations. Nevertheless, the figures following are offered in order to give persons unfamiliar with California practice a quantitative idea of the character of cementing operations there, but the figures should be construed merely as approximate.

Each hole is assumed to be in good condition, with no large caves or other unusual conditions. The figures are prepared to cover cementing of the casing at least 1,500 feet below the surface. For shallower jobs, less cement than the quantities given is used.



A. METHOD OF ROTATING CAS-
ING WHILE CEMENTING WITH
PERKINS OUTFIT.



B. CRUMPTON PACKER.



C. STONE PACKER.

Approximate quantity of cement used per job in cementing water strings with any one of the pumping methods, according to California practice.

Size of casing.	Quantity of cement used, tons.
10-inch-----	6 to 12
8½-inch-----	4 to 8
6½-inch-----	3 to 7
4½-inch-----	2 to 4

PROPER CONDITION OF HOLE AND OF CEMENT MIXTURE.

Numerous general conditions affecting the various cementing processes have been left for consideration as a whole rather than under each method.

The ultimate shape of the cement mass when set, and its distribution, radially as well as vertically, have much to do with its effectiveness. It is well known that a string of casing will not hang concentrically within the hole, that neither casing nor hole will be absolutely straight, and that at many points the casing will be in contact with the wall of the hole. It is impractical to drill a hole enough larger than the casing to prevent conditions such as described. When the cement is forced up the hole outside the casing there will be no cement at such points of contact, and there will be a deposit on the opposite side of the casing (see *B*, fig. 4) ranging from 3 or 4 inches up to several feet thick in caving formations. A local projection of the wall in contact with the casing here or there will probably not jeopardize the result of the cementing job. If, however, the contact points are so numerous that they constitute a line of contact connecting a water sand above with the bottom of the casing, thus permitting the water to flow into the oil or gas bearing strata along this line, as indicated by the arrows in *B*, fig. 4, the cementing job has failed. When this condition arises the cement is said to have channeled around the casing.

The casing is not protected at the contact points from corrosive water, and, although it would be highly desirable to protect completely the entire string of casing against contact with ground water, such protection is mechanically impossible with cement alone.

4, figure 4, in the writer's opinion represents a typical well-performed cementing job in a mud-fluid hole. The cement has been forced up around the irregular projections of the sides of the hole, filling the large crevices, and trapping mud here and there in the smaller crevices. It seems unlikely that the cement would wash all the mud out of these small spaces. On this feature hinges a much-argued question as to the advisability of a thick mixture, 40 pounds of water to 100 pounds of cement, or a thin mixture, 60 pounds of water to 100 pounds of cement. The writer's advice is to use the

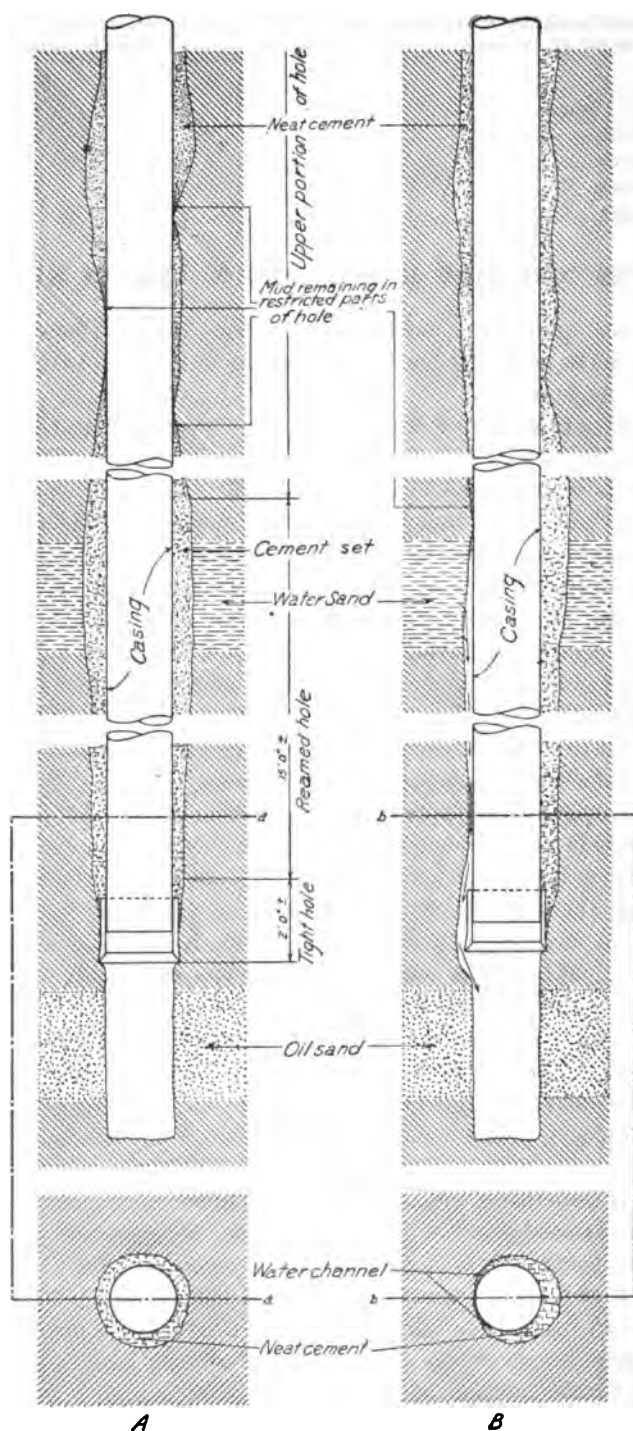


FIGURE 4.—Cross section of cement filling around casing in a well. A, Where the hold has been underreamed; B, where there has been no underreaming.

thick mixture, and if the physical conditions of the hole make it unwise to thin the mud, or, for other reasons, washing of the hole is deemed advisable, 5 to 15 barrels of water may be run ahead of the cement in either tubing or casing methods. This advice is based on the well-known fact that Portland cement when mixed thin will grade out on settling, leaving a fairly compact cake at the bottom of the column after long standing, and grading to a mushy chalk at the top. Intimate contact of cement particles is essential to a firm bond and proper setting in the cement mass. When cement is mixed with an excess of water the finer particles settle more slowly than the coarser ones, thus producing the grading tendency and attendant weakening of the mass. The greater the excess of water the more pronounced are these effects. Cement manufacturers have worked faithfully and with considerable success to develop a cement that will show this grading action as little as possible, but have not been able entirely to overcome it even in the best cements on the market. Some of the ordinary cements made for building purposes will not set at all if mixed with 60 per cent or more of water by weight.

It may be worth while for anyone cementing wells to take a thin batch of cement and let it set under water in a quart preserve jar or a tall bottle. After 10 days, when the container is broken off and the cement is tapped with a nail or point of a lead pencil, the variation in hardness from bottom to top will be evident. Moreover, any cement when mixed with a great excess of water has its ultimate strength greatly reduced, and the time required for it to set is also greatly increased, a most important factor in cement used in oil or gas wells. Moreover, when cement is mixed with more water than is needed to satisfy the chemical requirements, the water will work to the top, or, differently expressed, the cement will settle through the water to the bottom of the containing vessel, whether it is a jar, a concrete form, or an oil well. Hence, as regards a thin mixture in a well, the cement will tend to settle to the bottom of cavities and crevices, leaving the water to fill the upper parts, thus defeating one of the chief objects of cementing. Although it is difficult to eliminate this caving tendency, it can be reduced to a minimum by filling all irregularities of the hole as completely as possible with a permanent material. Any cement mixture that is fluid enough to pump will contain an excess of water, and the settling action described will take place to a greater extent as the excess of water is increased. Hence this condition should not be augmented by adding an unnecessary excess of water. It seems probable that there will be no cement in some small spaces surrounding points where the casing is in contact with the wall of the hole. These spaces will doubtless be small, judging from the sharp impression made by a mold on cement

mixed as here advised, and taking into consideration that in a well the cement is under the pressure of a column of water or mud that in some wells amounts to a thousand pounds per square inch. These minute spaces will naturally be filled either by the mud fluid or by water, according to which material happened to occupy the hole when the cementing job commenced. A, figure 4 (p. 56), illustrates this condition in an irregularly shaped hole, with cement filling the larger spaces and mud the smaller crevices.

Although it is practically, if not physically, impossible to prevent contact at some points between a string of casing and the wall of the hole, it is practicable when using cable or pole tools to prevent such contact from occurring within 10 or perhaps 20 feet of the bottom of the water string by enlarging the lower part of the hole by underreaming. Such enlargement of the hole must not extend too far vertically. In the writer's judgment 15 feet vertically is a good average for underreaming, but the larger the diameter of the reamed part of the hole, the better. If a casing shoe is used, as is universal in California practice, it is advisable to leave a couple of feet of tight hole at the bottom of the well. (See A, fig. 4.) If the hole is reamed for any great distance, say 40 to 60 feet, the casing will probably come into contact again with the wall near the bottom and defeat the entire object of the reaming. On the other hand, if only the lower 10 or 20 feet of hole is enlarged, the constricted part above will center the casing and hold it entirely clear of the walls below.

The advantages gained by the use of cement may be summarized as follows:

1. All large spaces are filled with a firm, impervious material which will tend to prevent sagging or bending of the pipe, and, by filling the cavities before nature gets a chance to do it, will retard caving of the walls of the hole.
2. The cement will prevent the escape of the mud fluid from behind the casing.
3. Cement has been known to form a water-tight barrier between oil and water sands cased off behind the same string of pipe, thus preventing intermingling of the oil and the water.

PREPARING A WELL FOR CEMENTING.

There has been considerable controversy on the advisability of washing a hole free from mud, or as nearly free as possible, before the cement mixture is pumped in. When cement was first coming into general use for oil and gas well purposes, oil men considered it absolutely essential to thoroughly wash the hole with water prior to cementing. Experience gained with the use of mud flush in the

rotary and circulatory systems of drilling has occasioned a revision of opinion. Instead of being a detriment, mud fluid is now rather generally considered a benefit to cementing operations.

Before further discussion, it is well to define the term "mud fluid." Such a fluid may vary from clear water with a specific gravity of 1 as the lower limit to a pasty mass of mud with a specific gravity of about 1.45 as the upper limit for California muds. Mixtures of mud fluid used in drilling in different California fields range in specific gravity from 1.05 to 1.15, that is, they are 5 to 15 per cent heavier than water.^a The term "mud fluid" is erroneously applied at times to a mixture of mud containing fragments of shale and sand. Such cuttings may thicken the mud fluid but should not be considered as a part of it, as they will settle in a hole and bridge above the couplings of a string of casing and cause it to "freeze" or to become "collar bound." If this mixture be run through a flume or settling tanks to remove the cuttings the remaining fluid will not settle except to a limited extent, after which the settling action practically ceases, provided the air is excluded. J. O. Lewis, petroleum technologist of the Bureau of Mines, conducted some interesting experiments on the settling of mud fluid and has in the bureau's San Francisco laboratory samples of mud fluid taken from drilling wells. They are in long glass tubes. Some of these have stood in the tightly closed tubes for two years. If a slender glass rod be inserted in any of these tubes it will settle immediately by its own weight to the bottom of the tube; in other words, in two years' time there has been no appreciable tendency for the mud to harden or cake. In its present condition, after standing two years, this mud could be handled by pumps almost as easily as when obtained from the drilling well, and is a good illustration of what is meant by the term "mud fluid."

Besides having the mud free from drill cuttings it must be thin enough to be lifted on the rising column of cement. If the mud is allowed to thicken it will become so plastic that it will hang tightly in the more restricted parts of the hole and allow the cement to break through at one or two points and thus channel. The mere fact that there is a considerable difference between the specific gravity of heavy mud and that of even a thin cement mixture does not mean that the cement will lift the column of mud ahead of it, as the factor of viscosity, or, as regards thick muds, one might say plasticity, is important. To illustrate, a mixture of mud^b so thick that it would

^a Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: Bull. 134, Bureau of Mines, 1916, p. 14.

^b The clay used was from rotary-drilled holes in the Sunset Midway field, California.

not drop out of an inverted beaker had a specific gravity of 1.41, as compared with water, yet a cement mixture with 60 per cent of water by weight would have a specific gravity of 2.2. If cementing with such mud and cement mixtures were possible, it is unlikely that the cement would lift such a column of thick mud without channeling through it.

Wherever mud flush is being used, care should be taken to have all the fluid in the hole free from cuttings before cementing operations are commenced. After the hole has been drilled, circulation should be maintained, and, if necessary, the mud should be thinned until all cuttings have settled out in the flume. This precaution may cause a delay of an hour or two, but will usually save several hours before a job is finished.

In setting casing into a rotary hole, where this precaution has not been taken, it frequently happens that when the casing is still several hundred feet off bottom the fluid in the hole is so thick with cuttings that the pumps delivering at 400 pounds per square inch fail to start circulation. Not infrequently under such conditions the casing is pulled up 40 to 60 feet into the derrick with the pumps operating to keep it full of mud. The fittings at the top of the casing are then closed and the casing is lowered as rapidly as possible into the hole. This method will doubtless set up, within the pipe, pressure far greater than the capacity of the pumps and will often start circulation around the shoe, or sometimes through the side of the casing by splitting a joint of the pipe with the consequent trouble and loss.

The internal pressure thus set up is most difficult to compute, as the condition of the hole, the thickness of the mud, and many other factors unknown and variable enter into the problem. For example, if the hole is crooked much of the weight of the casing may be carried by friction. The velocity with which the pipe is lowered also plays an important part in the pressure built up.

It was impossible to obtain experimental data as to the amount of pressure so developed, for the reason that as soon as the danger was realized by the operating and contracting companies, they issued orders that when circulation could not be started with the pumps, the casing must be pulled out of the hole until the pumps could start the mud, when the casing was to be worked to bottom with pumps maintaining circulation all the way.

EFFECT OF AGITATION ON CEMENT IN A WELL, AND PRECAUTIONARY MEASURES.

Putting cement into a hole in which there will be any considerable agitation by movement of water or gas is useless. Such agitation will either prevent the cement from setting at all, or will cause it to set in such a loose condition that cementing will be far less effective

than a good landing job, with a column of mud back of the casing and with no cement at all. By proper use of mud-laden fluid such conditions have been overcome at many wells.

In shutting off top water two methods are used for quieting gas—the use of mud fluid and the use of hydraulic lime. Local, geological, and mechanical conditions vary so greatly that it is difficult to generalize in regard to the best method of procedure. If the casing is set in an open hole there is no way to make a satisfactory seal between it and the wall of the hole; thus any water or gas encountered is free to heave all the mud out of the hole from behind the casing if there is sufficient pressure in the sand. If the agitation is not violent, it can often be quieted by circulating thick mud fluid into the casing and up outside it. If trouble from gas or water can be foreseen from previous drilling, it is advisable to set and, perhaps, cement a larger string of casing above the troublesome sands. When they are reached with the water string the space between the pipes can then be closed off with gas clamps. The mud can then be pumped in under high pressure. This method has another great advantage—the operator may use thinner mud which is not so easily cut or made to froth from gas pressure as a thick fluid, and it will also penetrate much farther into the gas or water sands.

After such a mudding job has been completed, and usually from time to time during it, the water string must be moved up and down the hole about 25 feet or enough to “pass couplings.” This will prevent mud from building up on the pipe and the sides of the hole, thus restricting the subsequent passage of cement to a small channel with the consequent results already discussed. The cement may then be placed by any of the various methods to suit the conditions.

All cementing processes depend for their success on two fundamental requisites which the operator should fulfill to the best of his ability, or not use cement at all. These are (1) effective preparation of the hole to receive the cement, and (2) thorough mixing of the cement in the smallest proportion of water that will give the necessary fluidity.

Too frequently experienced men become so accustomed to an oft-repeated piece of work that the work is performed mechanically. Thus cement is sometimes mixed with a large excess of water and pumped into a hole that is gassy and is poorly prepared to receive the cement. If the two requirements previously mentioned are faithfully met and a good grade of Portland cement is used, the operator has every reason to look for a successful shut-off. When about to cement for the first time it is advisable to make a few tests with the cement to be used and the water available for mixing it. If the local supply is satisfactory and the cement mixed with it will set firmly under water and in a reasonable time, the operator may pro-

ceed as described. There will be little opportunity for underground water to interfere seriously with the setting of the cement, as such water will usually be driven back from the hole by fresh water or mud. Of course, such interference is chemically possible, and when thorough washing of the hole, before cementing, was in vogue, the chances of such interference were greatly augmented. However, if the hole is properly prepared and the cement mixed with suitable water, the writer is of the opinion that the character of the underground water need not occasion great anxiety.

USE OF PACKERS.

The use of packers for shutting off water can hardly be treated in detail with any degree of satisfaction without going deeply into the subject of drilling methods.

The packers used in California practice are usually placed either on tubing or on small sizes of casing in order to restrict the diameter of the well to promote flowing. Packers are also set on casing below a leak in the water string, thus preventing the water from entering the productive part of the hole. A wall packer, in the sense that it is set in the wall of the hole and not inside another string of casing, is almost never used in the poorly consolidated shales and clays constituting the formation overlying the oil zones in these fields.

An exception is the packer built by Mr. C. W. Stone, of Maricopa, Cal., for a special job in the Sunset field, where a flowing water sand had to be cased off in order to utilize the oil measures below. Several attempts made with the usual cementing and mudding methods gave only temporary success. A packer that proved successful was made around the shoe joint with old bull rope and bail wire. To make the packer, the shoe joint was placed with the upper end down on the derrick floor. A board at the roof made a convenient place from which to work. Hemp bull ropes were cut in 35-foot lengths and untwisted. The strands were doubled and the loop ends tightly wired to the pipe immediately under the shoe until the compressed hemp mat was flush with the outer edge of the shoe and extended entirely around the pipe. The loose hemp was tied every two or three feet with a strand of soft rope, as shown in Plate XIV, *B* (p. 54). The packer was then complete, and, after being turned right end up, was placed as the bottom joint on the string of casing. Of course, such a packer might be placed anywhere in the string so as to set wherever most desirable. As the packer entered the hole each soft rope string was cut, thus leaving the long strands of hemp free to spread out at any enlargement of the hole. When the pipe was set any movement of the water past the packer drew the loose hemp into the

passage and automatically clogged it. Mud settling on top of the packer also assisted in its effectiveness. This type of packer has three great advantages, as follows: Effectiveness; nominal cost (old bull rope and bail wire); does not occasion material difficulty if the casing is to be pulled.

BOTTOM-WATER JOBS.

When a water sand has been penetrated at the bottom of the well below the productive formation and separated from it by a parting, it is not always easy to plug off the water so tightly that when the fluid is all pumped from the hole the plug will have sufficient strength to hold back the water. A reinforced-concrete plug has proved effective in many such wells. The reinforcement consists of old wire drilling cable cut into 10-foot or 12-foot lengths. These are burned sufficiently to draw the temper. Each piece is doubled on itself and fastened with bail wire to others treated and bent in the same way. All the free ends of the cable are laid the same way in the bundle, which is of such size that it will slide freely down through the casing. These bundles are dropped into the casing with the bent ends down and the cut ends up, so that the package will not catch in the pipe and hang, for if such a wad of annealed wire ever bridges in the casing it would cause much trouble. As an extra precaution against such an occurrence, tin cans may be used over the lower end of the bundle. The cans, must of course be wired on tightly. The hole is thoroughly cleaned out before the first bundle of wire line is put in. Each bundle is tamped firmly into place with the tools, a flat-bottom bit being used. This process is repeated until a firm foundation has been built and the soft wire mass wadded thoroughly into the irregularities of the hole. On top of this mass a canister containing wet concrete is then lowered, being attached to the tools with wire, and is broken up with the tools and pounded down on top of the wire line. The canister is made of light galvanized iron 4 or 5 feet long and of any convenient diameter to suit the size of the hole. These canisters should have soldered joints and pointed bottoms to obviate any danger of catching on the sides of the casing.

Concrete of about the same consistency as for surface work is mixed in a box on the derrick floor and poured into a canister. Several canisters may be placed before more wire line is put in. The plug is thus built up of alternating layers of concrete and wire line pounded together until the hole is filled to the desired point. The plug is then allowed to set quietly with the hole full of fluid for 10 days or 2 weeks. This method usually gives a substantial plug, but should not be used if there is much likelihood of deepening the well, as it makes a plug that is difficult to drill out.

Nearly all oil or gas wells diminish in diameter with depth, hence in plugging off bottom water, any bailer or other container used must generally be of small diameter. This necessitates more runs to cement a deep hole and is objectionable, owing to the greater amount of time required to run the bailer or container to bottom and pull it out for another trip. For example, in a 3,500-foot hole $4\frac{1}{2}$ inches in diameter, it is a tedious task to dump 35 to 40 sacks of cement, and very likely the first part will take its initial set before the last batch can be dumped. To avoid this difficulty a string of tubing may be run in and hung a few feet off bottom with both the hole and the tubing full of water. The entire amount of cement to be used can then be mixed in one batch and poured by a swing connection from the mixing box into the top of the tubing. Water can then be immediately run into the tubing on top of the cement. By its own weight the cement will gravitate quickly to the bottom of the hole and set there in a solid mass. This system is, of course, one variation of the tubing method as applied to bottom-hole work without the use of pumps.

If the bottom water has sufficient head to make it flow, it is likely to wash the cement away before it can set, thus leaving a water channel through the plug which will wash larger and allow more and more water to pass as time goes on.

A most ingenious and highly successful scheme for handling such conditions was used by Mr. C. W. Stone, of Maricopa, Cal. He collected a quantity of old hemp rope, unraveled it, and chopped the strands into pieces about 4 inches long. These were wadded into tin containers of 4-inch stove-pipe joints about 3 feet long. Each joint was battered in at one end to prevent the escape of the hemp. Of course, different conditions will require more or less hemp or burned wire line, but in this particular instance 12 tins of chopped hemp were put on bottom, care being taken not to break the tins. If the tins are broken at this stage of the work, the whole plan is defeated, as the hemp will be washed away by the flowing water. Four bundles of burned wire line 4 feet long were then run in on top of the tins, each bundle being pushed firmly to bottom with the tools. When the fourth bundle had been placed, the tools were hitched to the beam, and tamping commenced. A flat-bottom bit was used, and the tamping was continued until the wire had been firmly driven down on top of the hemp. This tamping broke the tin containers, liberating the chopped hemp which rose with the water current and lodged in the mat of wire line above. Under such conditions the hemp would naturally be carried by the water first into the more open channels, and later into the more restricted water courses, and so on until all flow stopped. More hemp and more wire line might have to be used in some jobs than in the one described. In this instance several layers were used until fin-

ally the flow of water diminished, getting less and less at each stroke of the tools until it ceased flowing altogether. A concrete cap was then placed on top of the plug and built up to the desired level. Generally these layers are made 5 to 10 feet thick. Mr. Stone has tested these plugs by permitting them to stand 42 hours after the water level has been lowered 2,000 feet in the hole and found them satisfactory.

When feasible it is good practice to drill clear through a bottom water sand and 5 or 10 feet into the shale below, clean the hole thoroughly, and build the plug from the bottom of the hole up through the water sand and well up into the formation above. The plug then takes a position like the core of a stopcock and is subjected to lateral pressure from all sides but not to the heaving thrust exerted on a plug extending only a little way into the water sand, where reliance is placed entirely in the hold the plug may have in the overlying formation.

To indicate what the heaving tendency of a flowing water sand may be on a plug that does not extend into and form a tight seal with the formation below the sand, assume that the bottom water rises to the ground surface in a 2,000-foot hole. When all fluid is removed from the hole, the plug will be under a heaving pressure equal to the static pressure of a 2,000-foot column of water. This pressure is equal to 870 pounds per square inch, or a heaving pressure of about 22 tons on a plug in an 8-inch hole.

TESTING A WATER SHUT-OFF.

Whenever the character of the formations and methods of drilling will permit, the driller should observe and note in the log book any peculiar characteristics of water encountered, such as freshness or salinity and sulphur content, also the natural level of the water in the hole, and whether there is any change in water level when various sands are encountered.

After the cementing has been done and the time allowed for setting has elapsed, the effectiveness of the work must be tested. The mere fact that the job has been done in a workmanlike manner and by approved methods does not fulfill an operator's obligation to himself, his neighbor, or society in general. The test consists of two phases. In the first phase the water is bailed out, leaving a dry hole, or, at least, the water should be lowered sufficiently below the natural water level of the locality to create a reasonable external pressure on the casing—1,000 to 2,000 feet is usually sufficient. The well is then allowed to stand 8 to 24 hours, or more. This part of the test is made before any residual cement has been drilled out of the casing, and is for the purpose of demonstrating that there is no leak of any kind in the pipe itself. In the second phase of the test the

residual cement is drilled out and a few feet of new hole is drilled ahead of the casing. Unless there is danger of a gas blow-out or some other weighty consideration is adverse, all the fluid should be bailed out of the well and the hole allowed to stand 12 to 24 hours. If the test shows that the cementing job is not satisfactory, corrective measures must be taken. If the second part of the test shows that the water is not shut off, effort must be made to determine whether the water is coming around the shoe or through a leak in the pipe itself. If the water is coming through a leak in the pipe and not around the shoe, drilling may be continued and the well completed in the usual way. After the inner or oil string has been set, it may be cut off somewhere between the shoe of the water string and the leak, and the upper part pulled out and set back on top of the lower section with a packer between the two sections, thus preventing the water from entering the oil sands by way of the hole in the water string. The packing should be of more permanent material than rubber.

Plate XIV, *C* (p. 54) shows a packer known in the West Side Coalinga field as the "Crompton packer." It is used to combat corrosive water. Much trouble has been experienced in this part of the field by ground water eating through the water strings after a few years' exposure. The packer illustrated is set by the weight of the upper part of the oil string. This packer is strong and simple in construction. The packer has a sliding inner sleeve about 5 feet long, so arranged that it can not pull entirely out of the outer sleeve that is screwed into a coupling on the bottom of the upper section of the oil string. The inner sleeve is wrapped with square hydraulic hemp packing, as shown in the illustration. Any machine shop experienced in making oil-well devices can turn out one of these packers without a working drawing.

USE OF HYDRAULIC LIME FOR SHUTTING OFF WATER.

Realizing that well cementing as commonly practiced was not always effective, Mr. E. A. Starke, chemist for the Standard Oil Co. of California, applied himself to the problem of devising improvements. Backed by the liberal financial support and hearty cooperation of his company, Mr. Starke has done much experimental work in the laboratory and in the field with various kinds of cementing materials. If results of this work were published, they would form a valuable contribution to the literature of petroleum, and it is hoped that some day the industry may be so enriched. The material in this section is used by the courtesy of the Standard Oil Co., which furnished the data, Mr. Starke making many valuable suggestions.

As outlined previously, the problem that confronted the operators was how to make a water-tight and permanent shut-off in the poorly

consolidated shales and clays overlying the oil measures in some of the California fields. This work is especially difficult when there is agitation in the hole by seepage of gas or by flowing or migrating water. In the early days, in shallow territory and with otherwise favorable conditions, water could be shut off with a fair degree of satisfaction by landing a water string, as has been seen. Cementing was introduced and greatly increased the effectiveness of easy jobs and made possible others that had formerly been impossible. As drilling methods progressed, even cement was not entirely satisfactory at some wells, as it did not set. At first the suggestion was made that cement would not set in contact with oil. Laboratory tests demonstrated that cement will not only set in contact with oil but when mixed with a considerable quantity of oil along with the water.

If a water shut-off is to be made in a well which has not entered the oil or gas sands, and if there is only one string of casing in the hole, so that pump pressure can not be applied, it may be difficult, and perhaps impossible, to get sufficiently high pressure with mud to plug the pores of a gas or water sand. If the mud is excessively thick the cement tends to break through it and "channel" up the pipe instead of surrounding it in a solid mass. To thin the mud may cause a blow-out of gas which will in all probability "freeze" the pipe.

In general, there are three avenues of approach to the problem outlined, as follows:

1. To get a cementing material that will set under agitation and also possess the other requisites of moderate cost, ease of handling, etc.

2. To get a cementing material that will stop the agitation so that Portland cement will set, and that also possesses the desirable commercial and mechanical qualities.

3. To get a cementing material that possesses qualifications of both the first and second class.

The Standard Oil Co., as a result of its varied experiments, is using hydraulic lime as the material to be classed under the second of the three headings mentioned—that is, for retarding or eliminating agitation that would prevent the setting of Portland cement.

Hydraulic lime has properties differing widely from those of an ordinary hydrated building lime. The latter, when mixed with water to form a putty, will remain under water in this condition indefinitely, whereas hydraulic lime sets firmly under water. The setting is gradual, and although a pat will be fairly firm after standing 24 hours in air it would probably require 18 to 24 days to set firmly under water. This test may be made in an ordinary drinking glass, and perhaps save some costly mistakes. Although such a test is a guide, the author has not sufficient data on the use of hydraulic

lime to state that every lime that will set hard under water is fit to use in shutting off water in drilling operations. An operator contemplating the use of hydraulic lime will do well to make the test mentioned and other rough tests, such as the thickening effect when dry lime is mixed with the drilling mud. All such test mixtures should be allowed to set under water.

CHEMICAL PROPERTIES OF HYDRAULIC LIME.

Table 2, following, presents analyses of different brands of cement and of hydraulic lime. One is struck with the similarity of the constituents and the diversity of their proportions. The cements represented in the table are typical of the best grades of Portland cement, manufactured especially for oil-well purposes, and vary little from each other in chemical composition. Of course, the fineness to which a cement is ground has much to do with the time required for its setting, a feature not shown by the chemical analysis. The analyses of hydraulic lime show wide variation. The German lime, although somewhat high in silica and low in iron oxide and alumina for use as Portland cement, would seemingly sinter to a fair grade of natural cement. There is an essential difference between hydraulic lime and cement. Cement rock, either natural or proportioned by analysis, is sintered to incipient fusion and then ground very fine to manufacture cement. Hydraulic lime, in contrast, is burned and hydrated, but is never sintered.

TABLE 2.—*Chemical analyses of cement and hydraulic lime.*

Constituent.	Formula.	Brand of Portland cement.			Brand or source of hydraulic lime. ^d				
		Golden gate cement. ^a	Santa Cruz oil-well cement. ^b	Mount Diablo oil-well cement. ^c	German.	Pacific Lime & Plaster Co., San Francisco.	Cartersville, Ga.	Man-kato, Minn.	Common or quick lime. ^e
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica.....	SiO ₂	20.89	19.38	22.36	25.87	19.51	15.04	18.10	1.00
Ferric oxide.....	Fe ₂ O ₃	3.37	5.31	2.51	8.13	12.40	.72	5.02	1.30
Alumina.....	Al ₂ O ₃	7.09	7.15	7.17					
Lime.....	CaO.....	63.47	63.70	62.39	55.44	39.20	51.12	40.68	97.00
Magnesia.....	MgO.....	1.32	2.13	1.39	1.14	20.61	29.53	29.17	.70
Sulphuric anhydride.....	SO ₃	1.19	1.48	1.45	1.44	1.66	Trace.	2.05	.....
Ignition loss.....		1.54	1.04	2.09	1.96	.46	3.54	4.56	.....
Manganese oxide.....	MnO.....							.42	.....
Carbon dioxide and volume.....					6.02	6.17			.....
Specific gravity.....		3.12	3.20	3.12					.....

^a Pacific Portland Cement Co., San Francisco, Cal. Analysis made by the company.

^b Santa Cruz Portland Cement Co., San Francisco, Cal. Analysis made by the company.

^c Cowell Portland Cement Co., San Francisco, Cal. Analysis made by the company.

^d Analysis furnished by Dr. E. A. Starke, San Francisco, Cal.

^e Marks, L. S., Mechanical engineer's handbook, 1916, p. 568.

Interesting and instructive as the chemical analyses are, they do not alone furnish the knowledge of physical properties that is so

important. The calcium and magnesium in hydraulic lime are in the hydrated form— $\text{Ca}(\text{OH})_2$ and $\text{Mg}(\text{OH})_2$ —but contain no water of crystallization. The name “hydraulic” comes from the property of setting under water. Without this property a lime can not properly be classed as hydraulic lime. The hydraulic lime used by the Standard Oil Co. is manufactured by the Pacific Lime & Plaster Co., of San Francisco. It is not a natural lime, but is proportioned and mixed by analysis. Such a lime has a marked advantage over a natural hydraulic lime in that its components may be varied at will to give it special qualities for certain kinds of work, as is possible with Portland cement.

When hydraulic lime comes into contact with finely divided silica and the aluminum silicates of the shales and clays, it combines to form complex gelatinous silicates the exact chemical formula of which is not known. This jellylike mass not only swells perceptibly in setting but adheres tenaciously to the walls of the hole. Any carbon dioxide in the gas of a well will react with the calcium oxide of the lime to form chalk, the reaction causing a further swelling of the mass. When such action takes place between the grains of a sand the result is to cement the sand into a compact mass surrounding the hole. The lateral thickness of this mass is, of course, dependent on the depth of penetration of the lime solution into the formation. It is frankly admitted that a neat hydraulic lime has a tensile strength of only about two-thirds of that developed by neat cement. Such a consideration has little to do with the value of cementing material in an oil well, so long as the material will set and when set will have a tensile and compressive strength sufficient to stop the flow of water or gas from agitating the Portland cement that is placed between the lime-plastered wall of the hole and the casing to be cemented.

Milk of lime (finely divided hydrated lime that has been steam slacked) will in some wells combine with the silicates and aluminates of the formation to form gelatinous silicates, and will prove as satisfactory as hydraulic lime. This reaction depends upon the favorable chemical and physical properties of the formation and therefore can not be universally relied upon. If hydraulic lime containing finely divided silica and iron and aluminum oxide is used, its essentials are self-contained and hence it has a far better chance to do its work under unfavorable conditions than the milk of lime, and is therefore preferable.

Hydraulic lime is mixed separately with water and pumped into the well ahead of the cement. When the two-plug or Perkins system of cementing is used the lime solution is pumped into the casing on top of the column of mud and ahead of the first plug; thus the cement follows immediately behind the lime solution in its course down the

inside and up the outside of the casing. The main advantage claimed for the use of hydraulic lime is that when a solution of mud, as ordinarily used in drilling, is mixed with a solution of hydraulic lime a muddy sort of plaster is formed which so coats the formation as to greatly reduce and often entirely prevent agitation from gas or moving water. This action takes place when the hydraulic lime passes out of the casing and mingles with the mud in the bottom of a well. The writer suggests further that this mixture of lime and mud will make a firmer bond with the formation than neat Portland cement, and that the Portland cement will in turn adhere more firmly to the mud and lime plaster than it will to the ordinary mud-smear side of a hole.

SPECIAL USES OF HYDRAULIC LIME

If mud flush is circulated continuously as drilling progresses, the mud usually fills the pores of porous sands or gravels. Occasionally the mud runs away into such sands or gravels instead of returning to the surface. Circulation is immediately lost. Nearly every driller has either had such an experience at one time or another or knows of where it has occurred, and realizes the difficulty of reestablishing circulation. Teams are often kept busy for days hauling mud and manure, sawdust, etc., to be mixed with the mud in an effort to clog the passages. The Standard Oil Co. handled an obstinate hole of this kind in the Antelope Hills by mixing hydraulic lime and manure with the mud in the suction box. This mixture filled the channels in the sand and circulation was restored. Though the lime may have cost money, whereas the other materials were free, the difference was more than offset by the difference in hauling and labor charges, to say nothing of the risk of allowing the hole to cave. This risk increases greatly the longer the time before circulation is restored. For work of this kind the dry lime may be shoveled into the liquid mud and mixed with shovels or hoes, and by circulating it through mud pumps. The lime need not be mixed with water and then poured into the mud.

There is still opportunity for investigation and improvement in this phase of exclusion of water from oil and gas wells. If hydraulic lime, or some other more suitable substance that will set hard after being mixed thin, is forced into each water sand when encountered, thus changing the sand into a hard lens of impervious and permanent sandstone surrounding the casing, much expense may be saved in drilling operations. It might be possible with such a system to drill wells with cable tools and use only one string of pipe, whereas under present practice one or two additional strings are used as conductor pipes and water strings. The saving thus effected would be great, provided the cost of sealing the sands could be kept moderate.

If such a process were developed, it could be applied to intermediate water, permitting simultaneous production from the oil sands above and below the water with the use of only one string of surface casing or an oil string in territory where the oil sands did not stand up well enough to make an open hole possible. To handle intermediate water by such a method would, of course, require a packer of some kind set below the upper producing sand and above the intermediate water sand. The packer would prevent the lithifying solution from entering the upper oil measures, and thus, perhaps, seriously affecting production.

It is the writer's hope that the foregoing discussion may not only acquaint operators with what has so far been done in the use of hydraulic lime, but may induce them to conduct further investigations bearing on the subject and to make their results known, whether successful or not. A knowledge of the limitations of a process is just as essential as an understanding of its scope.

WATER PROBLEMS IN THE MID-CONTINENT FIELDS AND METHODS FOR HANDLING THEM.

Far too much drilling has been done in the oil industry at large with a view to striking oil and then selling or leasing the property rather than with the intentions of operating the wells until the last barrel of commercially recoverable oil has been marketed and the wells have been thoroughly and effectively plugged. Moreover, it may be said that some operators have manifested more interest in obtaining a clearance paper in the form of a "plugging affidavit" than in seeing that the plugging has been properly done. Such operators, through ignorance or criminal indifference, will frequently employ a contractor who is far more interested in getting his money than in fulfilling his contract.

It is difficult to conceive of conditions that make it permissible to abandon an oil, gas, or prospect well without effectively plugging it as the casing is withdrawn. An excuse for not plugging an abandoned hole is occasionally heard to this effect: "The well would not make a bailer of oil a week, so there was no use going to the expense of plugging a hole like that." The knowledge that water may travel through a sand from a nonprofitable well and spoil many valuable oil wells and much property or perhaps embarrass some future mining operations is not so general as might be desired.

GENERAL CONDITIONS IN MID-CONTINENT FIELDS.

In the Mid-Continent fields there are three outstanding requirements regarding protection from water, as follows: (1) Protection of a valuable formation from a water stratum shut off behind the

same casing, (2) shutting off water from the hole by casing, and (3) shutting off bottom water.

With mud fluid the first requirement can be met, and mud fluid should be used wherever the formation to be protected is of value anywhere in the district. In regard to the second requirement, all too little effort is made toward a permanent shut-off, and the writer believes that much of the water trouble, whereby production is decreased or producing expenses increased, is caused by top water breaking into the hole from around the shoe and through leaking joints or casing that have become corroded.

Bottom water is likewise a cause of much trouble and expense. The engineers of the Bureau of Mines who have investigated conditions in the Mid-Continent fields are all of the opinion that a great reduction in costs and loss of production could be effected by the repair of old wells and by greater care in shutting off water in new wells. One of the greatest opportunities to-day for increasing efficiency in the Mid-Continent old fields is in the correction and prevention of water infiltration.

Common faults in the Oklahoma fields are as follows: Not setting casing up tight enough, not using good casing shoes, not selecting good casing seat, using rubber-wall packers for permanent shut-offs, nonconformable shut-offs, not protecting casing against corrosive water, and not insisting on absolutely tight shut-offs.

These evils arise partly from the contract system wherein the drillers of the wells have little interest in making permanent shut-offs and partly from a lack of appreciation on the part of the operators of the harm resulting from insecure shut-offs. Operators should insist that contractors make shut-offs that will be permanent instead of lasting only until the well is completed. Such temporary results are obtained with the rubber wall packers, which experience has shown to be far from reliable. Another tendency is for the operator to be satisfied when the water is "practically shut off," but experience shows that the little trickle of water in time enlarges and becomes a stream. Later in the well's life the operator complains about how much water comes in the same sand with the oil.

Cable tools are almost universally used in the Mid-Continent fields, and frequently without a calf wheel to handle the casing. The formations stand up well, so that drilling may be done without simultaneously carrying the casing. Usually the hole is made to a certain point according to local requirements, and then the entire string of casing is set at one time, as contrasted with usage in caving formations, in which the casing must be inserted a joint at a time, and often in short lengths of 5 or 10 feet, in order to keep the shoe in close proximity to the bottom of the hole. In the Mid-Continent fields it is customary to employ a casing crew under contract when

a string is to be set. The joints are usually set up by hand, frequently with only a rope sling. It is only with the deeper strings that the engine is used for setting up the pipe. Of course, even heavy casing will not stand the pull of a drilling engine on ordinary chain tongs without damage. When a producing well is to be shot to stimulate production, the water string often is pulled up well above the shot. Whenever possible, the water string should be set far enough above the producing sand to be safe from the damage of a shot, so that there will be no need of moving the string. Then if the hole back of the pipe be filled with fluid and the fluid in the pipe be baled or swabbed till its level is below the bottom of the water string before the shot is fired, the likelihood of damaging the pipe even by a heavy shot is decidedly lessened. The feature to be emphasized is the possibility of pulling a string of casing with several hundred feet exposed to the formation after it has been set for several years. In most California fields this can not be done.

Difficulties in the Mid-Continent region are accurately summarized by Lewis and McMurray,* as follows:

The natural conditions affecting the conservation of oil and gas are unusually complex in the Mid-Continent fields. There are a large number of sands containing gas, oil, or water, so that the drill may penetrate many different sands, and in every conceivable combination. Plate XV shows the combination of sands found in parts of the Oklahoma fields. At Blackwell, Okla., gas sands are found at intervals from within a few hundred feet of the surface to a depth of 3,400 feet. Gas is nearly always found associated with an oil pool, and may be in the higher parts of the same sand as the oil, or in sands above or below the oil sand. Pressures as great as 1,300 pounds per square inch have been found in some of the deeper wells and flows over 50,000,000 cubic feet daily have been reported from a number of wells. The formations resemble those in the fields of States farther east, and the wells are usually drilled under contract by the dry-hole method.

Under such complex conditions drilling in a dry hole is wasteful and dangerous, and to fully protect all the formations by the use of casings, packers, and bradenheads is often either impracticable or impossible. Occasionally the gas will interfere or prevent drilling until the pressure has been reduced. The gas is developed faster than it can be marketed, and to finish the well so as to keep it stored in the ground without waste delays the completion of the well by the dry-hole method and adds to the expense.

Operators on Indian lands in Oklahoma have been required by the Interior Department to conserve the gas and oil resources, and the authorities of the State of Oklahoma are requiring other operators to take similar precautions. The protective work is largely done with mud fluid, and many of the leading operators, both in Oklahoma and Kansas, are using this method, even where not legally compelled to do so.

* Lewis, J. O., and McMurray, W. F., *The use of mud-laden fluid in oil and gas wells*: Bull. 134, Bureau of Mines, 1916, p. 51.

In working up a new system of procedure, or in adapting an old one to new conditions, a few failures are to be expected, but these, if properly studied, become material assets by reason of the knowledge they furnish. Such failures have occurred with the use of mud-laden fluid in parts of the Mid-Continent field. Sometimes an operator will use muddy water, or else will pump into the well the muck from the mud sump, including sand, lime, and shale cuttings mixed together; another will have trouble with the pipe "freezing" before it can be set. One such instance was reported when the casing was entirely free to move about 5 or 6 feet up or down, but would neither pull above nor go below these limits.

SUGGESTIONS ON USE OF MUD FLUID AND CEMENT IN MID-CONTINENT FIELDS.

Since the use of mud fluid has become general in the Mid-Continent oil fields, local operators are developing special practices. Probably 2,000 wells have been mudded in and many of the operators are becoming experts in its use. The contentions of the Bureau of Mines have been amply justified, both as to the benefits of the proper use of mud fluid and as to the harmful results when improperly used. Success or failure has hinged primarily upon two factors—(1) the thickness of the fluid and (2) its freedom from sand, limestone cuttings, or coarse materials.

As stated elsewhere, mud fluid, being fluid, will not be shut off at the casing seat, but the casing must be set in such manner as to retain fluid behind it. However, mud fluid will force water back into its native formation and prevent it from entering the hole and thus gaining access to other formations behind the casing. In this way valuable oil, gas, or fresh-water and salt-water strata can be protected from an intermingling of their various contents though all lie behind the same casing. Several strings of casing, each securely landed, would otherwise be necessary.

The experience of the Empire Gas & Fuel Co. in the Eldorado and Augusta fields, Kansas, amply justifies this statement. Though the gas sands have been protected from underlying water sands only by mud fluid in the wells drilled to the deeper oil sands, water has failed to invade them, and the gas wells require only the occasional "bleeding" usually necessary. The operations in these fields demonstrate that it is entirely practicable to develop an oil field and at the same time protect and utilize the gas in overlying sands.

METHODS FOR SETTING CASING WITH MUD FLUID.

There are several methods in use for setting a string of casing with mud fluid back of it, and no one of these can be termed the best

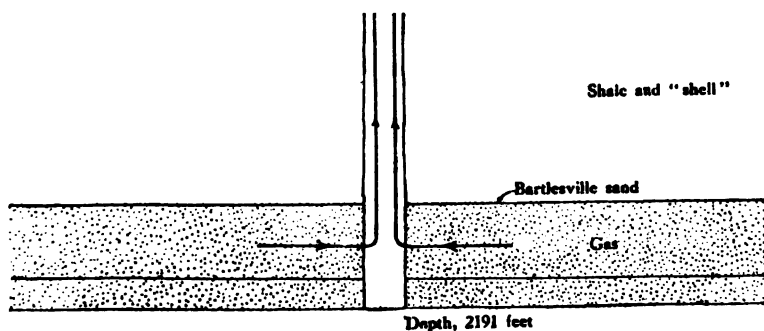


DIAGRAM OF WELL IN OSAGE COUNTY, OKLA.

Shows condition of well and way in which gas escaped to surface. Well was completed May 8, 1914, with an open flow estimated at 22,000,000 cubic feet. When shut in the gas cut under each string of casing, which were landed in shale, and escaped into the other sands. Gas had reached the surface as far as 600 feet from the well, and for a radius of 300 feet was issuing from the ground in large volume, when inspected on August 11, 1915.

or proper method for all conditions. Like all other oil-field operations, this should be done in the cheapest way that is consistent with safety and good mining.

For convenience, the various methods are summarized as follows:

1. Filling the hole with mud fluid with a dump bailer, or through casing, so that the wall of the hole will not be unduly washed. The casing is then pumped down as the mud circulates.
2. Inserting the casing to within a few feet of bottom and pumping the mud into it, finally circulating the fluid.
3. Inserting the casing and setting it on bottom, filling it with mud fluid and lifting it off bottom, and continuing pumping until satisfactory circulation is obtained.

In all these methods ultimate circulation is essential, and some means should be provided for testing the specific gravity for the outgoing as well as the ingoing mud fluid. By this means the operator will be able to determine when no further dilution of mud takes place from water in the hole, and by inspection of the mud he may determine when gas and oil, if any are behind the casing, are completely "mudded off."

Method 1 requires more time than either of the others, but may be applied wherever method 2 or 3 can be safely used, whereas neither of the latter two methods may always be applicable where No. 1 is safe; therefore method 1 is recommended when a doubt exists as to the advisability of using method 2 or 3.

Method 3 has been successfully used in the Eldorado and Augusta fields of Kansas. The Empire Gas & Fuel Co. has "mudded" some 300 strings of 12½-inch, 10-inch, and 8½-inch casing set at an average depth of about 1,500 feet. After the 8½-inch has been "mudded" and set as a water string at approximately 2,400 feet, the 10-inch and 12½-inch casings, which were also "mudded," are pulled. There has been only slight difficulty in pulling these strings after they have set one to seven months, and the practice has been amply justified in the localities mentioned.

This company reports the use of mud of 1.40 and 1.60 specific gravity without difficulty. This is heavier than engineers of the Bureau of Mines had thought would pass through the pumps. There is a greater variation in the relative specific gravity and fluidity of muds than had been anticipated. For example, the tests on all the previous recommendations had been made with mud from California fields, and the mixture of such mud with a specific gravity of 1.41 (41 per cent heavier than water) was so stiff that it would not run from an inverted glass and could not have been pumped.

The experience of the Empire company has shown not only that it is possible to reclaim the casing landed in mud fluid, but that much less trouble is experienced than in pulling the casing from other wells

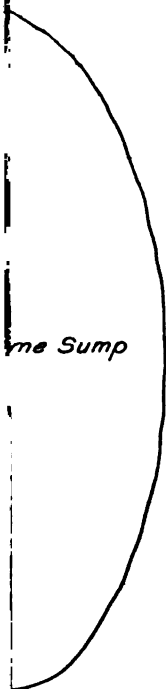
in the same field in which such fluid was not used. Great care is always exercised to exclude sand and limestone cuttings from fluid put into the hole.

Method 3 proved unsatisfactory for use in many wells sunk through the gas sands of the Cushing field, as the rush of mud around the bottom of the casing when the casing was lifted from its seat, frequently occasioned collapsing and sometimes bursting of the pipe. As a rule, in the Kansas fields mentioned, there is considerable water in the hole, both inside and outside of the casing. Thus when the casing is lifted, the internal column of mud fluid has to overcome the pressure of the external water column and its inertia, resulting in a greatly reduced velocity of the fluid as it passes out of the casing. Although there is water in the Cushing field in large quantities, in the early days it was usually blown out of the hole from behind the casing by the gas pressure as fast as it would enter the hole, thus eliminating any back pressure from the water.

In all three of the methods for placing mud fluid, considerable emphasis has been laid on circulation. Circulation is recommended when the casing is to be subsequently pulled, and is desirable on all jobs even if the sole object is the protection of strata behind the casing. However, it may occur that such protection is desirable where the necessary apparatus for circulation is unavailable. It may then be permissible to proceed as follows: Fill the hole with mud fluid; insert the casing, and seat it firmly on bottom; then remove the fluid from within.

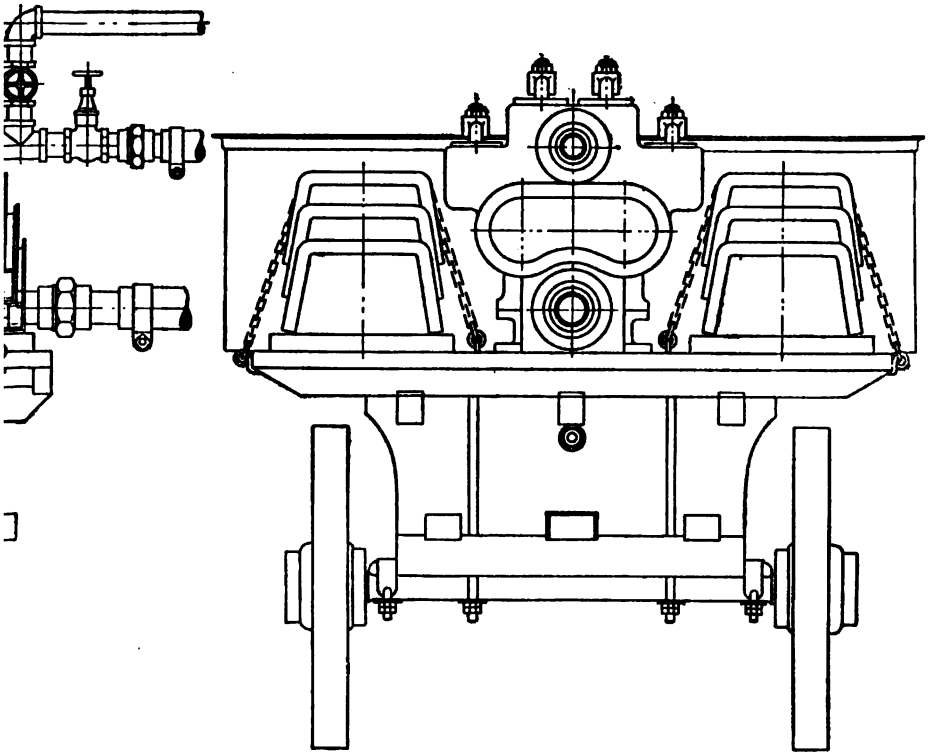
PREPARATION OF MUD FLUID.

To prepare the mud, the sump is divided into two parts, each with a separate dump box. Throughout the drilling work, efficient supervision is maintained to insure that the mud is dumped into one box and the other drillings into the other. When the well is ready for mudding, a pump mounted on a specially constructed truck is provided with suction and discharge connections, similar to that shown in Plate XVII (p. 77), is hauled up beside the mud sump. The mud fluid is mixed to the desired consistency by circulating through the pump and the mixing hose back into the mud sump. The specific gravity is determined by an hydrometer, so constructed as to eliminate any error of reading due to the viscosity of the fluid. When the mud emerges at the surface it is run into the pit and not returned to the well. This process is continued until no more cuttings or sand come up with the mud, and until the returned fluid is of a satisfactory specific gravity. The casing is then set firmly on bottom to afford a tight seat which will retain the mud behind the pipe when the fluid within has been removed.



me Sump

CTICE. THE
(3) THE BOX



The object of using a thick mud is twofold—first, to make the mud more effective against gas pressure; and, second, to get sufficient weight of mud without forcing it so far back into the oil or gas sand that it will penetrate into the nearby wells, as might occur if thin mud were used.

It is not an uncommon sight in the Eldorado fields to see two or even three wells within 100 feet of each other, each producing from different horizons and protected from the effects of unsystematic casing only by mud fluid.

Of course, this method of preparing mud may be used with any of the methods mentioned for getting it behind the pipe. The mud that collects at the lower end of the limestone and sand sump may also be used, as the coarse material settles out nearer the derrick.

The fact that mud from the limestone and sand sump has been used indicates that further experience may show that if the drillings receive proper settling before use the use of two sumps may be unnecessary. If a company is drilling only a few wells, or for some other reason the adequate supervision and inspection of mud throughout drilling operations is inconvenient, it would be an advantage to have available an outfit for preparing mud from the unseparated drillings. Such an outfit might be operated either by an association or local company, or under contract, and in the hands of a competent man would doubtless be satisfactory. Both contract and association systems have been used with entire success for handling the cementing operations in California fields.

A tentative design for a mudding and cementing outfit is illustrated and described below. Plate XVI shows the general arrangement, including a divided sump. Such an outfit may be used with either the one or the two sump system of handling the cuttings. Further experience may also indicate the desirability in some localities of a more thorough settling of mud than would be obtained by the sump method alone, particularly if the pipe is to be recovered after standing with mud behind it for a number of years. Plate XVII shows views of a portable mudding and cementing outfit mounted for transportation.

PROPOSED MUDDING AND CEMENTING OUTFIT FOR MID-CONTINENT USE.

The proposed mudding and cementing outfit shown in Plates XVI, XVII, XVIII, and XIX is designed with the following objects in view:

1. To prepare mud fluid effectively and to circulate it in a well.
2. To have the outfit so mounted that it can be set up at a well and repacked with a minimum expenditure of time and labor.

3. To use the equipment for a cementing outfit when cementing is to follow the use of mud.

The combined use of mud and cementing seems to the writer the most practicable method for much of the Mid-Continent work.

In the Mid-Continent fields cementing the water string is open to the following objections:

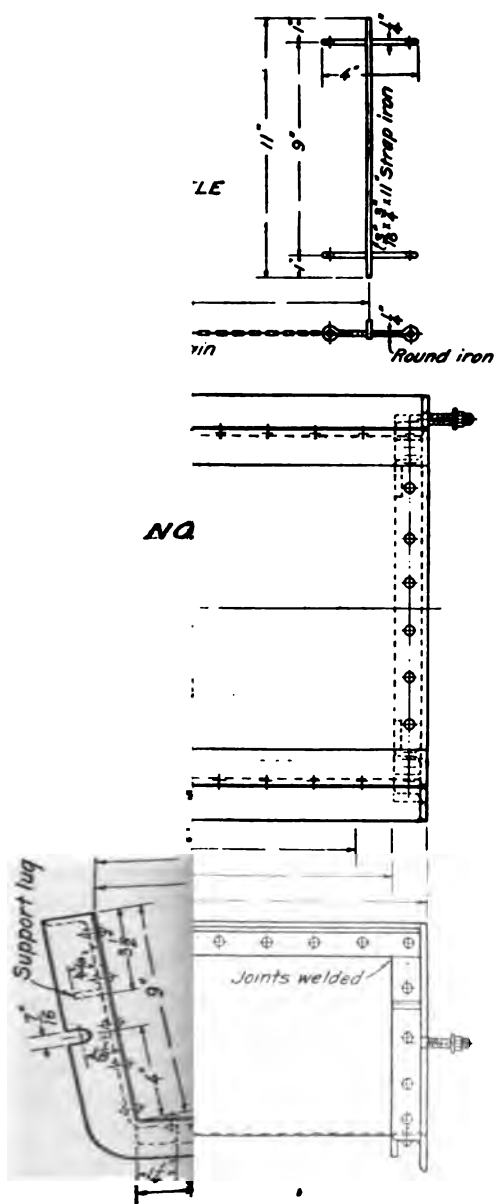
1. If the job on being tested after the cement has set 10 days or so proves a failure, considerable expense is entailed for redrilling or for putting in new casing, and frequently a reduction in diameter of the hole is necessary. When a well is to be abandoned, only that part of the casing above the cement is recoverable.

2. The cementing job itself is expensive and delays drilling considerably. This is particularly objectionable to drilling contractors.

To offset these disadvantages there is the one great advantage that a water string properly set up and "mudded" and cemented in the firm formations such as are common in these fields should be permanent throughout the life not only of the well but of the field.

Certain details regarding correct setting of the casing are important. A water string of, say, 8-inch pipe requires just as much force and probably more care to properly set up the joints than the same size pipe line. Frequently oil-well casing has a finer thread than line pipe, making "stabbing" (starting of joints) without cross-threading more difficult, and therefore requiring more constant vigilance. Moreover, the string must sustain the tensional stress of its own weight in addition to an occasional severe pull. After it is set it must withstand a severe collapsing pressure during its entire period of usefulness. If there is a leak in a pipe line, it appears when the line is tested, as does a leak in a water string. A leak in a pipe line can easily be repaired, whereas a leak in a water string may be attributed to "poor cement" or perhaps to "a stray water sand just below the pipe." The writer recommends that, in setting up the water string of an oil or gas well, the threads of each joint be cleaned of dirt and grit and then be painted with some suitable dressing, such as oil and white lead, and each joint set up firmly with the engine. This latter requirement necessitates some type of casing tongs that will distribute the pressure as uniformly as possible around the pipe, for ordinary chain tongs if used with the engine are almost sure to damage the casing. The force exerted by an engine is ample to crimp the pipe ends when they are forced into contact or to strip the threads. Judgment born of experience is the only guide for avoiding such trouble.

A steel casing shoe is advisable, particularly for the longer water strings. The suggestion of reaming the hole, as previously described (see fig. 4, p. 56, is also applicable here. The pumps used for circulating mud fluid may be used also for cementing, thus

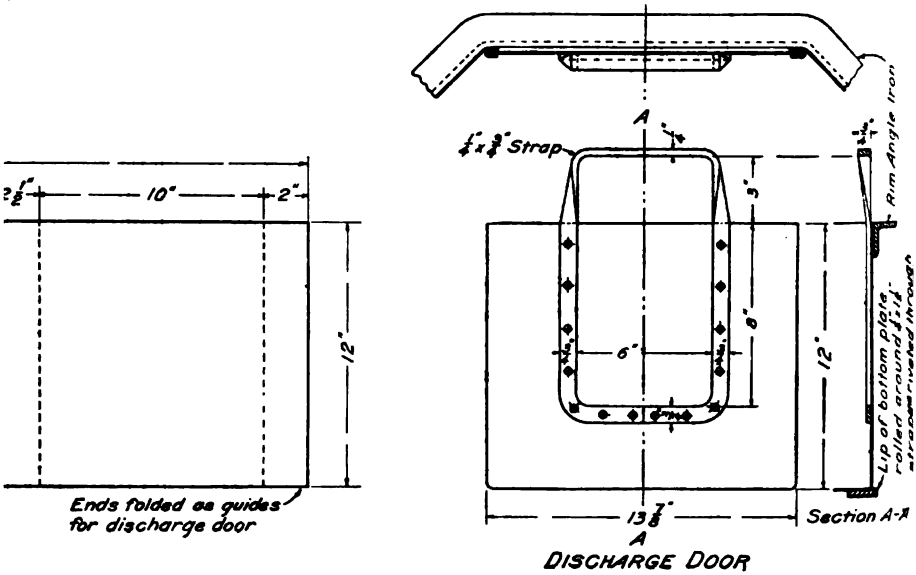


37

bolt

NOTE:- $\frac{1}{2} \times 1\frac{1}{2} \times 1\frac{1}{2}$ Angle iron and
No. 12 Galvanized iron used
throughout
All angle-iron joints to
be welded

7



maintaining circulation throughout the entire job. If the hole has been filled with mud fluid and the casing set without circulation, the cementing may be done by the dump-bailer method. As a rule, it will be unnecessary to use large quantities of cement—only sufficient to fill back of the water string for 40 to 60 feet above the shoe.

DESCRIPTION OF OUTFIT.

The mudding and cementing outfit, suggested for use in the Mid-Continent fields, is shown in Plate XVII mounted on a lumber wagon, so that it may be hauled from well to well either by a motor truck or a team. Were a contractor or association to operate the outfit, the use of a motor truck might prove advantageous. This must be determined by local conditions.

The design here presented is offered only as a suggestion to illustrate the possibility of developing a systematic and efficient method of procedure for such operations. The experience gained in the construction and use of such a plant as the one here outlined almost invariably suggests improvements to be made and apparatus that may be eliminated partly or totally, without impairing the utility of the whole. The three main parts of the outfit here described are:

1. Truck (motor or other type) of not less than 2 tons rated capacity.

2. Mud pump with necessary fittings and hose.

3. Settling flumes and cement box.

The pump should be of a type designed to handle mud fluid and of a capacity equal to that of an ordinary duplex steam-driven mud pump, 8 by 5 by 10 inches or 10 by 6 by 10 inches. The pump may be driven by any convenient power, according to local conditions. It may even be found convenient to provide for driving a geared pump from the engine of the truck. A duplex steam pump is shown in Plate XVII.

A settling flume 60 feet long is divided into six sections of approximately equal length and a corner settling box. These are shown mounted on the truck in Plate XVII and, in detail, in Plates XIII, XVI, and XIX. The general arrangement of parts when set up at a well is shown in Plate X (p. 42).

The design calls for No. 12 (United States standard) galvanized iron, reinforced around the end and along the edges of the flume sections with 1½-inch angle iron weighing 2.34 pounds per foot. Wherever the angles at the ends of the flume or in the sides of the corner box meet the rim angles, the joints should be coped and welded with an oxy-acetylene torch. All sheet iron should be tightly riveted with ½-inch rivets to the angle irons. It will be noticed that the bottoms of the lateral flumes as shown enter the respective sides of the corner box about 2 inches above the bottom of the latter, thus afford-

ing a catch pocket for the cuttings. The discharge door at the opposite corner of the box affords a quick and convenient means for removing these settlements.

Each flume section (see Pls. XVIII and XIX), as well as the corner box, is fitted with two wing bolts at diagonally opposite corners, with corresponding slots at the other corners. By this arrangement the various sections may be held firmly, end to end, in any convenient arrangement. This feature permits any combination of flume and corner box that the local topography or other conditions make desirable.

A set of removable riffles, made in six 10-foot sections having the general form of a rope ladder, is provided. The riffles, each 11 inches long and made of $\frac{3}{8}$ by $\frac{1}{4}$ inch strap iron, correspond to the rungs and should be placed about 18 inches apart. The sides of the ladder may be made of signal cord or galvanized-iron chain. Each section should be provided with snap hooks at one end and rings at the other, in order to facilitate combining them to fit any arrangement of flume. These "ladders" may be attached to a couple of suitable rods, one extending across the end of the flume at the well and the other across the aperture of the corner box connected to the discharge flume. These rods, of course, need not be attached to the flume in any way and can be made of the same material as the riffles, and should be about 19 inches long and have two drilled holes to take the snaps. Some provision must be made to hold the riffles on edge. One way of doing this is shown in Plate XVIII. Whenever the riffles become clogged with débris they may be lifted out and the flume cleaned with a square-nosed shovel, in far less time and much more thoroughly than if the riffles were stationary.

HANDLING AND CARE OF FLUMES.

The specifications for flumes and corner box provide for light construction, so light, in fact, that 2-inch angles may be found more desirable than the $1\frac{1}{2}$ -inch angles prescribed. Owing to the light construction it is necessary to handle the flumes with some care. It will be noticed that the flumes are made in lengths as follows: Two flumes, 10 feet long; 2 flumes, 9 feet 10 inches long; 2 flumes, 9 feet 8 inches long. Thus, when the flumes are inverted they may be stacked compactly. Lugs are shown welded on the end angles in the two long and the two intermediate sections to support the sections inverted on them and to prevent the sections from wedging together. It is assumed that during transit these flumes will be held firmly to the truck with chains, and lugs are provided at the bottom corners of each end angle of the two short flumes to hold the chains on the angle irons and prevent the chains from slipping to the galvanized-iron bottom.

SETTING UP THE FLUMES.

The higher end of the settling system is to be placed close to the well so that the returns will run into it. The lower end is to discharge into the mud pit *A* (Pl. XVI, p. 37). A slope of 1 foot in 20 provides a good grade for the flumes, this gradient to be altered as experiment may dictate. A partition of boards fitting the inside of the flumes is to be placed at some such point as *C* in Plate XVI, to prevent any mud from going toward the well during preliminary settling. If two sumps are used, shale and slate cuttings are supposed to be segregated in the sump *B* by means of the cut-out device shown at *D*, consisting of a door with flaps of belting nailed to its outer and lower edges, in order to insure comparatively tight contact whichever way it may be swung. By a tiller arrangement, easily made by bending a piece of 1-inch pipe, this door may be swung so as to send the sand and limestone cuttings into the one side of the sump, and the cuttings from shale, slate, or clay into the other. By placing the door outside the derrick and extending the tiller handle inside, cleaning around the door is facilitated, and the handle is also out of the way, on whichever side it may be swung. With these arrangements there is no excuse for an imperfect segregation of cuttings, as there is only one place to dump the bailer. By mounting back of the tiller a board scribed with the words "sand" and "mud" at its respective ends, the chances of error in operation will be reduced to a minimum. Such a sign will also serve as a reminder until the operation of the device becomes as much second nature as turning the throttle at the "headache" post to the left in order to shut off steam.

OPERATION OF MUDDING AND CEMENTING OUTFIT.

To prepare mud for use it is picked up from the sump *B* through the pump suction and circulated through the mixing hose back to the sump until a considerable quantity has been mixed. It is then discharged into the flume at *C* ahead of the wooden partition so that it will flow toward the corner box and around to the receiving sump *A*. It may be found convenient to eliminate the sump *A* and set the flume so that the mud fluid will be returned to sump *B*, minus the settlings, or it may be found more desirable and equally efficacious to use the sump *A* and only one main sump instead of sumps *B* and *B'*, thus eliminating the segregation of mud while drilling.

When the sump *A* is filled, the mud from it may be transferred to the well by operating the respective discharge valves and transferring the discharge line from the flume to the connections on the well casing. The mud is then admitted to the well by whichever system has

been found most effective in the particular locality (see p. 74) and the well is thoroughly "mudded."

A cement box 4 by 7 by 2 feet is specified, which should permit mixing 2 tons of dry cement with water in one batch. In the Mid-Continent field this quantity will probably be sufficient for the majority of cementing jobs.

COST OF FLUMES, RIFFLES, AND CORNER AND CEMENT BOXES.

To obtain a reliable estimate of the probable cost of the flumes, riffles, and corner and cement boxes, the plans were submitted to a large manufacturing company on the Pacific coast. This company can supply the stated parts, fabricated, for \$225 f. o. b. San Francisco, Cal. This figure is based on the prices of labor and material in November, 1917, and includes an allowance of 10 per cent for profit.

BOTTOM WATER.

Bottom water is common in the Mid-Continent and the Illinois fields. The bottom water is frequently found throughout a wide lateral extent. The term "bottom water" as commonly used in these fields refers to water underlying the oil and in the same sand with it, with no impervious stratum present to separate the water-bearing part from the productive part of the sand. A most successful method for excluding the water from a well under such conditions is that developed in the Illinois fields and known as the McDonald process.

MCDONALD PROCESS FOR CEMENTING OFF BOTTOM WATER IN OIL AND GAS WELLS.

The McDonald process was developed by W. W. McDonald, of Robinson, Ill. It has been briefly described in a bulletin* of the Illinois Geological Survey. This process is especially useful in a well that has been drilled or shot into bottom water, or where water has encroached on and claimed the lower part of an oil sand as depletion has progressed. It is particularly valuable in a shot hole, because its effectiveness is in no way impaired by any irregularity in the shape of the hole, nor by crevices or fissures.

For successful operation of the process, it is essential that the water sand take water when the level in the well is raised above the natural level of the water to be shut off. These conditions are typical of the underlying water in the Illinois pools.

Figure 5 shows a cross section of a well being cemented by the McDonald process. The tubing, usually 2-inch, is lowered into

* Kay, F. H., Petroleum in Illinois in 1914 and 1915: Illinois State Geol. Survey, Bull. 33, 1916, pp. 87-88.

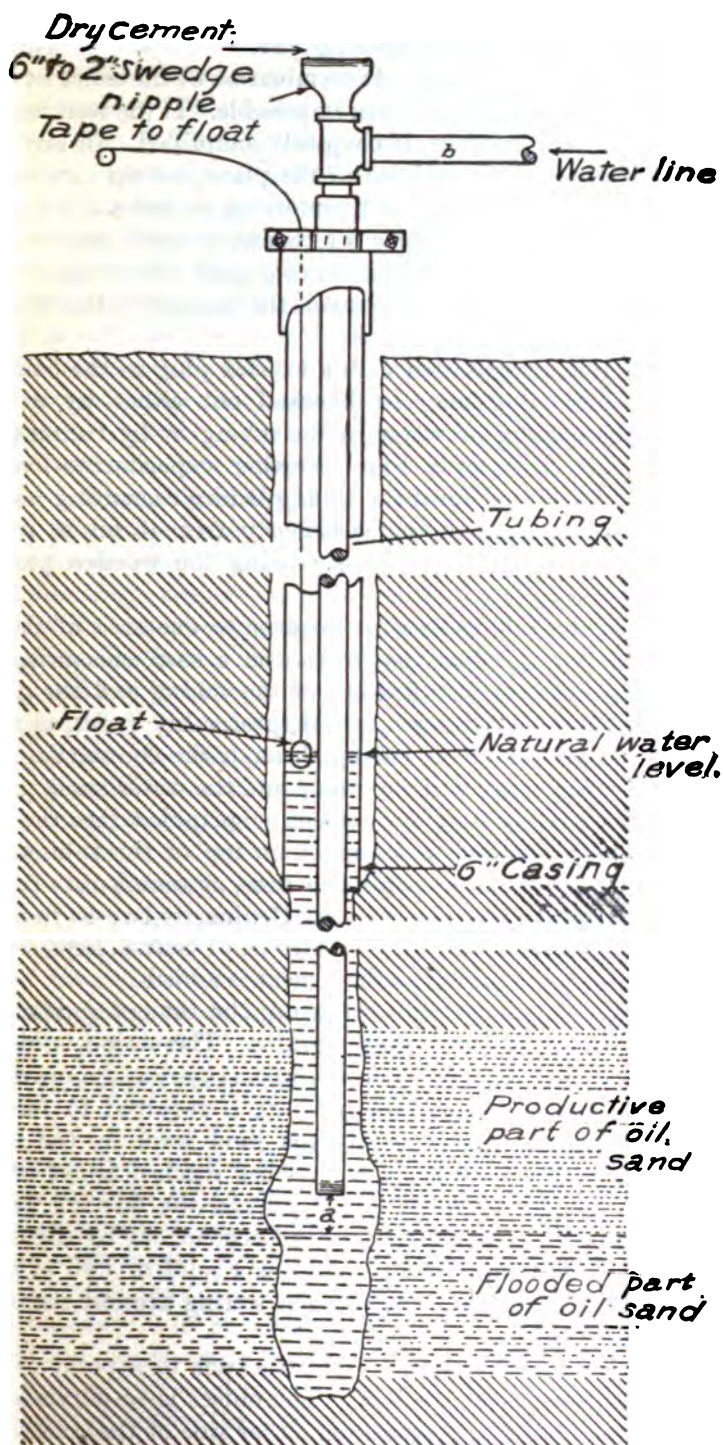


FIGURE 5.—Well being cemented by McDonald process.

the well until the bottom end is 2 to 4 feet above the plane of contact between the oil and the water-bearing part of the sand. This distance is designated a in figure 4. Determination of the exact situation of this plane may be difficult or even impossible. If the well has been shot into water, this difficulty is obviously simplified. In any event the operator estimates the position of the plane, taking care to keep on the safe side the first time, and preferring to make a low rather than a high estimate. If insufficient cement is used, more may be added at any time; but if the oil-bearing part of the sand be entirely or partly plugged off with cement, the damage to the well may be difficult to repair.

Tubing is commonly inserted with a wooden plug in the bottom to exclude oil. The plug may be knocked out either by exerting pressure on the column of water in the tubing or by running in a couple of sucker rods on a line. Further experimentation may show that the water run down the tubing before cementing, as later described, will rinse the tubing sufficiently free of oil to prevent any ill effect from it, thus perhaps making the wooden plug unnecessary.

If necessary, the tubing may be set over to one side of the hole to afford room for the float that is run on a steel measuring line. After the plug has been knocked out of the tubing and the natural fluid level of the hole measured, water, preferably fresh, is run or if necessary pumped into the tubing through the connection shown at b (fig. 4). This water will run away into the water sand. As the water runs down the tubing, dry cement is sprinkled into the 2 to 6 inch swage nipple, serving as a funnel, on top of the tubing. The cement is put in slowly, a handful at a time, at such a rate that one sack of cement will be placed per hour. Ordinarily two to four sacks of cement is sufficient for the job. Water is, of course, kept continually running down the tubing as the cement is added.

As the water runs away into the sand, the cement particles are caught in the interstices between the grains. The action is identical with that of a sand filter. As the voids become more and more clogged with cement, greater and greater pressure is required to force the water into the sand. Consequently the fluid level in the hole is correspondingly raised. When the level has reached about 500 feet above normal, no more cement is put in, and the flow of water is maintained only long enough to flush all cement out of the tubing. This done, it may be advisable to pull out a joint or two of tubing to preclude any possibility of the cement setting around the bottom of the string.

The water level is then allowed to settle back to a point 15 or 20 feet above the normal for the hole. The object is to obtain a close balance between the fluid pressures on either side of the cement with

a slight advantage in favor of the internal pressure as a precaution against any tendency there may be of the underground water forcing the cement back into the hole or causing sufficient agitation to keep it from setting. This status is maintained for about 24 hours by keeping a man at the well who runs in water in order to maintain the fluid level. Then the cement is allowed to set for a week or 10 days and the job is tested by pumping. If not enough cement has been used, the entire operation may be repeated as often as may be necessary to extend the plug up to the desired point in the hole. A time-saving variation is to run a small bob on a measuring line inside the tubing as soon as the cement has set firmly enough that its level may be detected with the bob and line. Then if insufficient cement has been used, more may be added without further delay.

In this process the cement fills the interstitial spaces and crevices in the water sand for some distance from the hole, in addition to forming a solid plug in the lower part of the hole. The process has marked advantages over merely filling the bottom of the hole with liquid cement.

Question may arise as to why the cement does not enter and collect in the pores of the oil-bearing parts of the sand, clogging them also. The explanation lies partly in the relative specific gravities of the water, cement, and oil, but chiefly in all probability in the immiscibility of water and oil, which naturally repel each other. Whatever the reason may be, the fact that the cement-bearing water selects the water-bearing part of the sand has been so thoroughly established for the Illinois conditions by Mr. McDonald's work that this phase of the problem need not deter a prospective user of the process. This statement applies only when the operator takes precautions to avoid the use of too much cement, which would, of course, plug off the oil as well as the water.

After the cement has set on such a job, to pump the water out of the oil sand and bring the oil back into the well may require several days, or a week.

USE OF LEAD PLUGS OR LEAD WOOL FOR SHUTTING OFF BOTTOM WATER IN A WELL.

In many parts of the Mid-Continent and eastern fields good use has been made of lead plugs for shutting off bottom waters where a strong, unshattered, and impervious stratum exists between the oil and the water sands. Lead billets or lead wool may be used. Before the lead is inserted the hole is plugged up to or bridged at the point where the lead is to be used. Wool is usually introduced in small bundles and tamped on top of the bridge or plug. Perhaps 200 to 500 pounds of lead wool will be thus used in a well, each bundle being firmly tamped before the next is placed.

There are many ways of manipulating the billet form of plug, two types of which are shown in Plate XX. The type shown in Plate XX, A, has a collapsible wooden base, which is held together by thin wire nails. This base is protected at the bottom by a tapered iron ferrule and is capped by the lead billet. When this plug is introduced into the casing and tamped with the tools on an obstruction such as the bridge, the wooden base telescopes, and, owing to the batter of its members, clearly shown in the plate, spreads to a firm hold on the side of the hole, thus increasing the strength of the bridge and affording a base on which to commence pounding the lead. The plug illustrated is to run inside a $5\frac{3}{8}$ -inch hole. The other plug consists of a hollow cylinder of lead 3 or 4 feet long and of suitable diameter for the hole, with a tapered cast-steel mandrel. When in place the lead cylinder is expanded against the wall of the hole by driving the mandrel down into it with the tools. As shown in the plate, the mandrel is cast with a mill-set to eliminate any chance, however small, of the mandrel working up out of the plug. This type of plug has a much larger effective bearing on the wall of the hole than that previously described, but is also more expensive, owing to the larger quantity of lead used. Neither type has as good an opportunity to fill an irregular-shaped hole as the lead wool. The chief advantage of the lead plug is the short time required to plug off bottom water when it is used. Moreover, no time is lost waiting for cement to set, as in the cementing methods.

Obviously a lead plug should not be used in soft formations, no matter how impervious they may be.

It is the opinion of the writer that in most wells the use of a concrete plug and perhaps some burned-wire line, as described under California practice, has a far better chance to be effective, as a cement plug will readily take the exact shape of a shattered or irregularly shaped hole. On the other hand, the stratum may be of such a character that a lead plug will not form an effective seal. In other words, it is not advisable to assume that underground conditions of an undeterminable character are favorable.

WATER PROBLEMS OF THE GULF OIL FIELDS.

In the oil fields of the Gulf coast of the United States cable tools are used only for redrilling, or perhaps for small deepening jobs. Practically all drilling is done by the rotary system. The physical characteristics of the formations penetrated are in a general way similar to those of the formations in the California fields. In both localities the drill penetrates poorly consolidated interbedded shales, clays, and sands, which offer comparatively little resistance to drilling. The chief difference between the formations of the two sections



A. COLLAPSIBLE PLUG.
a, Lead billet; b, Iron ferrule.



B. EXPANSION TYPE OF LEAD PLUG.

as regards drilling is that in the Gulf fields there are fewer hard, thick streaks or "shells," as they are commonly called, usually consisting of sandstone and impure limestone. Also, in the Gulf fields the shales constitute a much smaller and the clays a greater proportion of the strata penetrated than in California and usually give less trouble from caving.

NEED OF KNOWLEDGE OF SUBSURFACE GEOLOGY BASED ON COMPLETE WELL LOGS.

Although the value of the rotary system of drilling has been fully demonstrated in Texas and Louisiana, as well as in parts of California, the rotary system has one serious drawback, in that with this system it is difficult to determine with exactitude the character of the formations penetrated. Stated differently, the driller when drilling in a rotary hole filled with mud fluid is more likely to pass through a good oil sand and record it as sandy shale showing colors of oil than when cable tools are being used without mud and with the casing carried close to the bottom of the hole. Doubtless many drillers will disagree with this statement, but it has been rather generally accepted by those equally familiar with both methods of drilling.

In the Midway field of California, where rotary tools and cable tools have been used side by side, this feature has become well recognized. In that field oil sands have been penetrated with the rotary drill and have been recorded as sandy shale showing colors of oil and passed as unprofitable, the formation later delivering 500 to 1,000 barrels of oil a day for a long period of time. Such an instance was recently reported from the early drilling in this field. A company about to abandon an old well that had been drilled with a rotary drill tested an upper showing that had been cased off when the well was sunk. The result was a large yield of oil.

When rotary drills are used, difficulty is experienced in correlating strata in adjacent wells so as to set the various water strings in the same stratum to prevent water from migrating into productive strata.*

Under these conditions there is, of course, all the more necessity for careful and detailed geological work. In this connection two facts should be recognized.

First. The permanency of a driller's employment depends largely on his sustaining a reputation as a "hole maker." That is what he is paid for, and if he does not make the hole some one else will. Therefore his interest naturally centers around this feature of his

* For further discussion of conformable water shut-offs, see McMurray, W. F., and Lewis, J. O., Underground waste in oil and gas fields and methods of prevention: Tech. Paper 120, Bureau of Mines, 1916, 28 pp.

work, and the nature of the material drilled is of secondary importance except when it shows considerable gas or oil. This statement is not intended to belittle the importance of the driller's log, for in such work he is the eye of the geologist. The geologist should learn from the driller as much as possible about drilling methods so that he may properly interpret the logs and know what value can be placed on various samples.

Second. The geologist or engineer must maintain an intimate first-hand acquaintance with the drilling wells and must be so equipped that he can wash many of the samples at the well. He should obtain the driller's opinion not only of the material itself but as to how likely it is to be fairly representative of the part of the hole from which it is supposed to come. The driller, the geologist, and the company that employs them will profit by such cooperation. This is no idealist's dream but represents everyday practice in the mining of metallic as well as nonmetallic deposits, including oil. Nowhere in the United States do the natural conditions demand such work more urgently than in the Gulf fields. This is true not merely because it is difficult to obtain accurate samples with the rotary method of drilling, which experience has demonstrated is best suited for the local conditions, but because the chief oil-bearing strata of the district are covered by an overlap and do not come to the surface.* Their existence is proven entirely by the drill. Since all estimates as to the character, distribution, and continuity of beds of such prime economic importance is dependent on data obtained from well drilling, the utmost care should be used in obtaining all the information possible by proper sampling, and all data so obtained should be recorded and disseminated among operators for their mutual benefit.

Some companies operating in the Gulf fields have very efficient geological departments that are giving careful attention to such detailed technical work.

It has also been reported that some experimentation is in progress to develop a device that will pick up an accurate sample of formation from a rotary hole. This is a move in the right direction, and if such a device is perfected it should be of great value to the industry wherever rotary drilling is used.

Figure 6 shows a set of typical conditions assumed to illustrate the erroneous conception that may be formed of underground conditions if drilling data are incomplete, and the resulting economic loss.

View A is assumed to show the actual sequence of stratification. Well 1 is shown penetrating the water sand, but the log made no mention of it, although by good fortune the water string was landed

* Hayes, C. W., and Kennedy, William, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 212, 1903, p. 23.

below it, and the well proved a good producer from the oil sand beneath. Well 2 was drilled by a neighboring operator who had been given as complete a log of well 1 as was in existence. However,

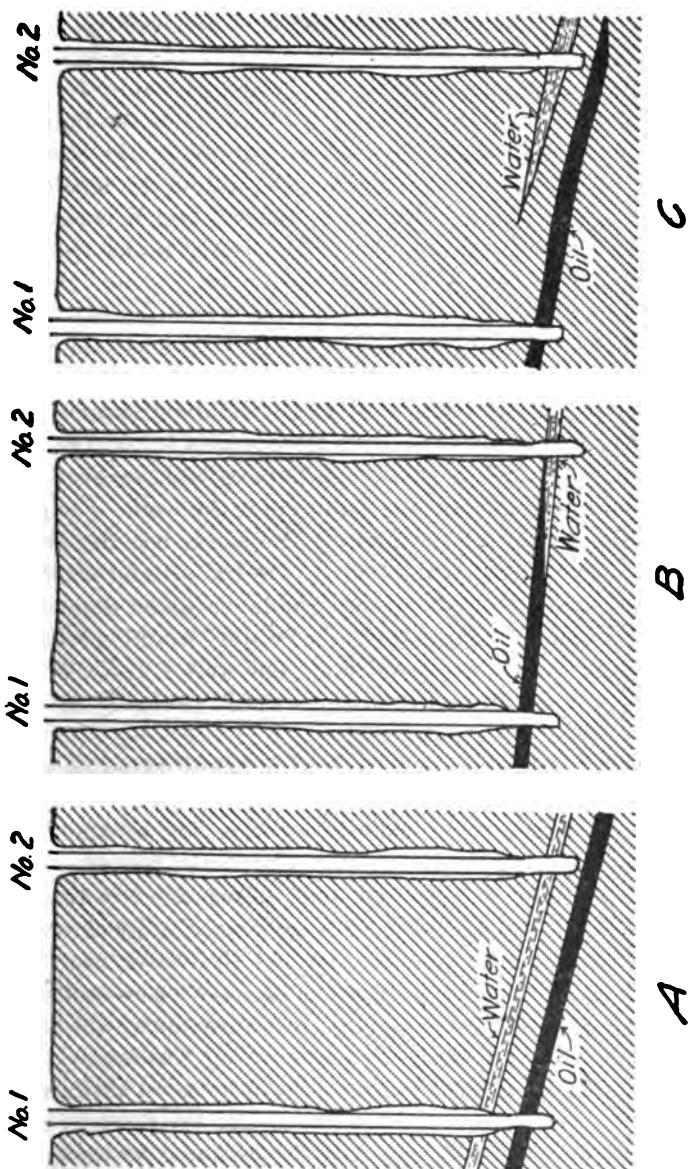


FIGURE 6.—Typical underground conditions encountered in well drilling.

as the log made no mention of a water sand having been penetrated only a few feet above the shut-off point, he landed the water string in well 2 at approximately the same depths as that in well 1, feeling

perfectly safe as the log of well 1 showed no sand of any kind for a couple of hundred feet above the oil sand.

The water sand in well 2, owing to its position just below the shut-off point where the oil sand was expected, might excusably be misinterpreted as indicating either an edgewater condition, as shown in *B*, or a lenticular condition, as shown in *C* of the figure. If lenticular conditions happened to be considered probable, further drilling in well 2 might tap the oil sand, exposing it to the ingress of the water above and occasioning a costly repair job or the abandonment of the well. For reasons stated later, the use of the bootleg to shut off water is not considered advisable practice, and it is therefore not suggested as an available method of procedure under these circumstances.

If the water in the water sand was not detected when penetrated by well 2 and the oil and gas commenced flowing when the productive sand was encountered, another set of conditions would arise. The internal gas pressure in the well might hold or support the mud plastered over the water sand, thus temporarily excluding the water from the well. After a period of perhaps a week, or even more, the pressure would decrease and the water enter the well. The gross production might remain approximately the same, but the net oil production would be greatly diminished. As the oil and water sprayed into the atmosphere together there would be great danger of their becoming emulsified. Moreover, the water would probably soon spread through the oil sand and flood out well 1 also. If this happened the true underground conditions would probably never become known.

This illustration might be varied to fit many types of conditions, but the details given will suffice to show the actual financial loss that may be occasioned by an incompletely kept log of the formations above those containing the gas or oil. The loss of money as well as of otherwise recoverable oil unfortunately is not as fully realized as if the preventability of the loss were more generally recognized. Such losses are considered preventable, as had the water sand in well 1 been recorded, drilling in well 2 would have been continued with utmost caution, perhaps at the cost of a little time, until the water sand had been passed before the water string was set.

The writer does not wish to leave the impression that in his opinion lenticular conditions do not exist in the Gulf fields, but rather that through lack of data they may be assumed to exist more frequently than is the case.

An inherent advantage of the rotary system of drilling over ordinary cable-tool drilling has greatly reduced the injurious effect on a field from unsystematic casing of wells. The advantage referred to is that the rotary hole is automatically plastered with mud during

the drilling, and the annular space between the wall of the hole and the casing is left filled with mud fluid when the water string is set, thus tending to prevent intermingling and dissipation of the contents of various sands above the point where the casing is set. To a great extent throughout the Gulf fields water strings are landed in sticky clay or gumbo.

Cementing of the water strings is practiced more in the fields of Louisiana than in those of Texas. The cement is usually placed by the casing method with one or two plugs, and although the work is in general executed similarly to that described in the section on California practice, there are many differences in detail. In Louisiana practice the second plug is usually a cylindrical piece of wood, about 18 inches long and of $\frac{1}{4}$ inch smaller diameter than the casing through which it is to work. To the bottom of this plug is nailed a wooden leg 2 inches by 4 inches by 3 or 4 feet long. On the top of the plug is nailed a disk of rubber belting which snugly fits the inside of the casing. In addition, four or five cement sacks are wadded on top of the belt rubber to act as packing. The first plug, when one is used, consists of a sack of shale cuttings twisted or rolled to fit the size of the pipe.

When circulation of the mud around the casing has been obtained and everything is in readiness for the cementing, the pipe is set on bottom and several stands of the 4-inch drill pipe, closed at the lower end, are lowered into the hole, thus displacing sufficient mud fluid to make room for the cement. The first plug, if used, is introduced and the cement is run in on top of it. The upper plug is placed on top of the cement, the pump connections are made to the casing, and the mud pumps are started after the casing has been lifted a foot or 18 inches off bottom. The cement is mixed with clean sand, in a ratio of two parts of cement to one of sand. The mixture, having a mushy consistency, is poured into the casing through a spout from the mixing box on the derrick floor. This feature is very different from the practice in California where no sand is used for this type of work, and the cement is mixed with water to such a consistency that it may be picked up by suction and pumped into the casing. Also it is not advisable in California to permit the full weight of the casing to set on the bottom for any considerable length of time, as the pipe will probably freeze if allowed to set long enough to displace the fluid with the drill pipe. In Louisiana practice, the regular drilling mud is used through the pumps to force the cement mixture down the casing. Such a procedure requires considerably less pump pressure than if clear water were used, owing to the greater specific gravity of the mud. Of course the mud can not be put through a meter, and no measurement is made of the amount used. The end point of the job is

determined entirely by the action of the pumps when the leg of the plug reaches the bottom of the hole. If everything has gone right the pumps will stall when the plug reaches bottom, and the casing is then set immediately. If there is any trouble, causing the plug to hang up in the casing, it is pushed to bottom with drill pipe which is, of course, standing in the derrick.

The circumstance most likely to cause trouble on such a job is a cave-in of the hole, which will shut off circulation. As in the Gulf fields the formations penetrated usually stand up well in a rotary-drilled hole, this danger is reduced to a minimum, making the system as used highly satisfactory for that locality. In cementing a string of 6-inch casing of, say, 2,500 feet it is customary to use about 25 sacks of cement and 12 sacks of sand. By the use of sand a greater volume of cementing material is obtained with comparatively small increase in cost, and without seriously reducing its strength, although, of course, such a mixture does not have the strength of neat cement.* If sand is to be used in this sort of a job, the mixture should be rather thick or mushy, as in a thin mixture the sand tends to settle to the bottom of the slug of cement as it passes down the pipe, and thus prevent the uniform distribution of sand and cement around the outside of the casing.

"BOOTLEG-PACKER" SYSTEM.

Although effort is made to set the water string in a suitable stratum between the lowest upper water and the first oil sand, this is not always accomplished; and as 6-inch pipe is customarily used for water string in 2,000-foot or 2,500-foot territory, such a failure becomes serious. It would probably be difficult, if not impossible, in many wells to loosen such a string of casing even were it landed without cementing, and to set or cement the string of 4½-inch casing would permit nothing larger than 3-inch pipe in the sands, thus restricting the size of the hole to an inconveniently small diameter. To obviate such a condition the "bootleg" has been devised and is often used, but is not recommended.

The "bootleg" (fig. 7) is made of canvas or leather riveted or sewed into the shape of an upturned truncated cone with the smaller end the same size as the exterior of the string of pipe on which it is to rest. The upper end is larger, so as to rest against the wall of the hole, but must, of course, be small enough to collapse and pass through the next larger pipe shown as of 6-inch diameter in the figure. The bottom of the "bootleg" is fastened with wire wrapping

* Humphrey, R. I., and Jordan, William, jr., Portland cement mortars and their constituent materials, results of tests made at the structural materials testing laboratories, Forest Park, St. Louis, Mo.: U. S. Geol. Survey Bull. 331, 1908, pp. 56-79.

to the 4½-inch casing just above a coupling and is placed at such a point on the string that it will set in a stratum of gumbo when the pipe rests on the bottom. The gumbo must, of course, be below the

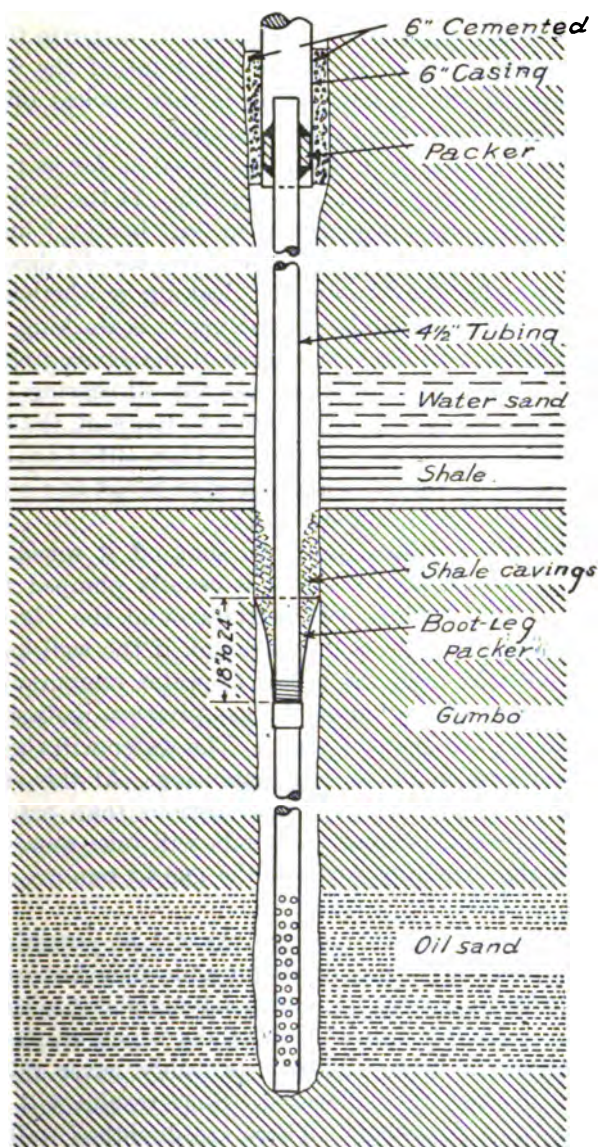


FIGURE 7.—“Bootleg” packer. Packer is made of canvas or leather sewed or riveted.

water sand, and ideal conditions require a bed of shale above the gumbo to furnish the requisite cavings.

The shale cuttings and mud are expected to settle around the “boot-leg” from above and make a tight joint between the casing and the

gumbo. The action is similar to starting a bridge in a hole by using a forked stick. Neither the bootleg nor the forked stick hold any considerable weight; merely enough to arrest the settling of debris until the latter commences to bridge. Sometimes in order to save casing the inner string, shown as of $4\frac{1}{2}$ inch diameter in the figure, is fitted with a packer to set in the bottom joint of the 6-inch pipe. The upper part of the $4\frac{1}{2}$ -inch string is then backed off at a left-hand nipple above the packer and pulled out.

Of course, a "bootleg" job should be tested as far as possible, but a thoroughly satisfactory test is not possible. If the well is pumped and brought in as a clean producer, then the "bootleg" has probably been successful; but if some water comes with the oil there is always a doubt as to whether the "bootleg" is leaking or whether the water is encroaching on the oil sands, or whether it is working around the $4\frac{1}{2}$ to 6 inch packer, and the very nature of the device precludes testing its effectiveness before drilling into the oil-bearing strata. No matter which way the water gains access to the well, the string with the "bootleg" on it must be pulled out. Then either another "bootleg" must be tried or the $4\frac{1}{2}$ -inch string must be set as a water string, which is by far the preferable method.

When water has not been properly shut off it sometimes shows immediately, but even then the well is usually pumped for a while with the hope that cuttings will settle around the "bootleg" and make a successful job. On the other hand, if the well has sufficient gas pressure to hold back the inflow of water temporarily, several days or weeks may elapse before the gas pressure is dissipated sufficiently to permit the ingress of water. The water will then probably make its appearance in the form of emulsion. At this stage of the well's life water on the sands is more serious than before the gas pressure is dissipated, because the sands will take more water and will not have the expelling force of the gas to remove it when the repair work has been completed.

To pull the $4\frac{1}{2}$ -inch string may or may not be possible according to the amount of friction on the string and other factors. Even if the $4\frac{1}{2}$ -inch string is loosened, it can not be removed without letting the mud from behind it into the oil sands, which are, as stated, in a most receptive condition and will probably never relinquish all of the mud and water thus admitted. Such results will not always follow the use of a "bootleg." There are doubtless wells in which water is shut off with such a device now producing in the Gulf coast fields after a long period of activity, never having shown any serious volume of water. Nevertheless, when a company attempts to use a "bootleg" it takes a chance of spoiling valuable property and diminishing the gross oil recovered from it, merely to make a comparatively small saving in first cost.

METHODS USED IN GULF FIELDS FOR PLUGGING OFF WATER SAND IN BOTTOM OF WELL.

An effective method of placing concrete for a bottom-hole job is the use of cement sacks. The concrete must be mixed to a thick consistency and the sack rolled in at the edge to form a canvas cylinder of such a size that it will slide freely in the casing. The sacks of concrete are pushed to the bottom and tamped into place with the tools. The process is continued until the plug is brought to the desired point. The precautions of properly cleaning the hole before work is commenced, described in the section on California practice, should be taken. If reinforcement is desired, burned-wire line may be used at intervals throughout the plug.

A successful plug has been built by using only the sacks from which cement has been dumped but not shaken, thus leaving some cement adhering to the inside of the sacks and retained in the fiber of the fabric. Six or eight sacks are wadded into a bundle and pushed down the casing with the tools and finally tamped to bottom with a string of free casing. The plug is thus built up, and when complete is held in place not only by friction but also by the weight of the casing which is set upon it. Only a few such jobs have been reported, but all of these have been successful.

SUMMARY.

Suggestions offered herein for handling the water conditions of the Gulf fields may be summarized as follows:

1. No effort should be spared to obtain as complete a log of each well as possible. A detailed knowledge of the three or four hundred feet of formation overlying the productive measures is far more important as a guide to subsequent drilling than a mere knowledge of the characteristics of the oil sands themselves.

2. Drilling data should be freely exchanged among neighboring operators.

3. If it be determined to get nothing smaller than a 4½-inch casing into the pay sands, an 8-inch water string should be set; then the 6-inch string may be used as a water string if the 8-inch pipe fails to exclude all the water. Moreover, the entire string of pipe, used for excluding water, should be left in the well. The upper part of a water string should never be cut off or otherwise removed from an active well. It may be recovered when the well is to be abandoned, if the hole is properly plugged.

The insurance against damage to the well and the property by leaving the entire water string in is worth many times the interest on the money tied up in the extra string of pipe.

ENFORCEMENT OF WATER PROTECTIVE LEGISLATION.

Another desirable feature not discussed in the foregoing text is the enforcement of adequate legislation regarding water protection, as an operator naturally hesitates to execute expensive work on his wells for precautionary measures without some guaranty that his neighbors will maintain their wells in an equally good condition. As a prerequisite to such legislation, the majority of operators must be alive to the exigencies of the situation and cooperate to inform the legislature of their needs and to assist it in drafting legislation. It is probable that the cost of effectively enforcing such a law would have to be met by a tax levied on the industry benefited.

Such work under the proper State department has several advantages. Every operator is held to a like character of work. A small company that can not afford to maintain a competent engineering department has the benefit of such a department by the payment of a comparatively small tax adjusted on an equitable basis according to the size of the company and its operations, a tax which it can easily afford and will usually be entirely willing to pay.

Finally, a few "standpatters" who are so constituted by nature that they assume a reactionary attitude toward all progress are forced to safeguard their own wells and property for their own protection and the public good.

CALIFORNIA LAWS RELATING TO OIL AND GAS WELLS.

California laws relating to the protection of natural resources of petroleum and natural gas flow:

AN ACT Establishing and creating a department of the State mining bureau for the protection of the natural resources of petroleum and gas from waste and destruction through improper operations in production; providing for the appointment of a State oil and gas supervisor, prescribing his duties and power, fixing his compensation; providing for the appointment of deputies and employees, providing for their duties and compensation; providing for the inspection of petroleum and gas wells; requiring all persons operating petroleum and gas wells to make certain reports; providing procedure for arbitration of department rulings; creating a fund for the purposes of the act; providing for assessment of charges to be paid by operators and providing for the collection thereof; and making an appropriation for the purposes of this act.

[Approved June 10, 1915. Amended 1917. Chapter 759.]

The people of the State of California do enact as follows:

Establishment of department—Appointment of supervisor.

SECTION 1. A separate department of the State mining bureau is hereby established and created to be known as the department of petroleum and gas. Such department shall be under the general jurisdiction of the State mineralogist. He shall appoint a supervisor who shall be a competent engineer or geologist, experienced in the development and production of petroleum, and who shall be designated the "State oil and gas supervisor," and whose term of office shall be four years from and after the date of his appointment.

Appointment of assistants—Compensation.

SEC. 2. For his services in the general supervision of said department the State mineralogist shall receive as compensation \$1,400 annually, which shall be in addition to his compensation fixed in section 2 of the act of June 16, 1913, relating to the State mining bureau. The secretary of the State mining bureau shall receive for his services in connection with the department of petroleum and gas a sum not to exceed \$600 annually, which sum shall be in addition to his compensation paid from the funds of the State mining bureau.

The supervisor shall receive an annual salary of \$6,000, and shall be allowed his necessary traveling expenses. The State mineralogist may, at the request of the State oil and gas supervisor, and subject to the civil-service laws of the State, appoint one chief clerk at a salary of not to exceed \$1,800 annually; twelve office assistants or stenographers, each at a salary not to exceed \$1,200 annually; four geological draftsmen, each at a salary not to exceed \$1,500 annually; four petroleum engineers, each at a salary not to exceed \$2,400 annually; twelve inspectors, each at a salary not to exceed \$1,800 annually.

The additional salary herein authorized to be paid to the State mineralogist and the secretary of the State mining bureau, and the salaries of the supervisor and of the deputies, clerks, stenographers, assistants, and other employees, shall be paid out of the funds hereinafter provided for at the times and in the manner that salaries of other State officers and employees are paid.

Duties of supervisor.

SEC. 3. It shall be the duty of the State oil and gas supervisor so to supervise the drilling, operation, and maintenance and abandonment of petroleum or gas wells in the State of California as to prevent, as far as possible, damage to underground petroleum and gas deposits from infiltrating water and other causes and loss of petroleum and natural gas.

Appointment of deputies and attorney.

SEC. 4. It shall be the duty of the State oil and gas supervisor to appoint one chief deputy and five field deputies, one for each of the districts hereinafter provided for, and prescribe their duties and fix their compensation, which shall not exceed \$4,000 per annum for the chief deputy and not to exceed \$3,600 per annum for each field deputy. Such deputies shall serve during the pleasure of the supervisor. He shall also employ an attorney at a compensation not exceeding \$3,000 per year, payable out of said fund, who shall also be attorney for each district board of commissioners; such commissioners may allow additional compensation to such attorney in actual litigation. The supervisor, the deputies, and the attorney shall not be subject to the civil-service act.

Duties of deputies.

SEC. 5. Each deputy appointed by the supervisor shall be a competent engineer or geologist, experienced in the development and production of petroleum. At the time said deputy is appointed, notice of such appointment shall be transmitted in writing to the board of commissioners of the district for which said deputy is appointed. Said notice shall be given either personally or by mailing a notice of said appointment to the post-office address of each commissioner. No appointment shall be final until a period of 10 days shall have elapsed from the mailing of said notice to said commissioners. In the event the majority of the commissioners notify said oil and gas supervisor in writing before the expiration of 10 days from the date of said notice that the appointment of said field deputy is disapproved by them, then and in that event said field deputy shall not be appointed, but said oil and gas supervisor must appoint some other individual, as in this section provided. Each field deputy shall maintain an office in the district for which he is appointed, convenient of access to the petroleum and gas operators therein. The office shall be open and the deputy shall be present at certain specified times, which shall be posted at such office.

SEC. 6. It shall be the duty of each deputy to collect all necessary information regarding the oil wells in the district, with a view to determining the presence and source of water in the oil sand, and to make all maps and other accessories necessary to determine the presence and source of water in the oil sands. This work shall be done with the view to advising the operators as to the best means of protecting the oil and gas sands, and with a view to aiding the supervisor in ordering tests or repair work at wells. All such data shall be kept on file in the office of the deputy oil and gas supervisor of the respective district.

Records and their use.

SEC. 7. The records of any and all operators, when filed with the deputy supervisor as hereinafter provided, shall be open to inspection to those authorized in writing by such operators, to the State officers, and to the board of commissioners hereinafter provided for. Such records shall in no case, other than those hereinafter and in this section provided, be available as evidence in court proceedings, and no officer or employee or member of any board of commissioners shall be allowed to give testimony as to the contents of said records, except at such court proceedings as are hereinafter provided for in the review

of the decision of the State oil and gas supervisor, or a board of commissioners, or in any proceedings initiated for the enforcement of an order of the supervisor, or any proceeding initiated for the enforcement of a lien created by this act, or any proceeding for the collection of the assessment levied under and pursuant to the provisions of this act, or in criminal proceedings arising out of such records or the statements upon which they are based.

Orders by supervisor—Agents of operators.

SEC. 8. It shall be the duty of the supervisor to order such tests or remedial work as in his judgment are necessary to protect the petroleum and gas deposits from damage by underground water, to the best interests of the neighboring property owners and the public at large.

The order shall be in written form, signed by the supervisor, and shall be served upon the owner of the well, or the local agent appointed by such owner, either personally or by mailing a copy of said order to the post-office address given at the time the local agent is designated, or if no such local agent has been designated, by mailing a copy of said order to the last known post-office address of said owner, or if the owner be unknown by posting a copy of said order in a conspicuous place upon the property, and publishing the same in some newspaper of general circulation throughout the county in which said well is located, once a week for two successive weeks.

Said order shall specify the condition sought to be remedied and the work necessary to protect such deposits from damage from underground waters. For this purpose each operator or owner shall designate an agent, giving his post-office address, who resides within the county where the well or wells are located, upon whom all orders and notices provided for in this act may be served.

Rejection of supervisor's orders, and appeal.

SEC. 9. The well owner or his local agent may within ten days from the date of service of any order from the supervisor, file with the supervisor or his deputy in the district where the property is located, a statement that the supervisor's order is not acceptable and that appeal from said order is taken to the board of commissioners. Such appeal shall operate as a stay of any order issued under or pursuant to the provisions of this act.

Districts, commissioners, election, recall.

SEC. 10. For the purposes of this act the State shall be divided into five districts, as follows:

District No. 1, including the counties of Los Angeles, Riverside, Orange, San Diego, Imperial, and San Bernardino.

District No. 2, the county of Ventura.

District No. 3, including the counties of Santa Barbara, San Luis Obispo, Monterey, Santa Cruz, San Benito, Santa Clara, Contra Costa, San Mateo, Alameda, and San Francisco.

District No. 4, including the counties of Tulare, Inyo, and Kern.

District No. 5, including the counties of Fresno, Madera, Kings, Mono, Mariposa, Merced, and all other counties in California not included in any of said other districts.

There shall be elected at the times and in the manner hereinafter provided, district oil and gas commissioners for each such district, as follows:

For district number one, five; for district number two, five; for district number three, five; for district number four, seven; for district number five, five.

Said district oil and gas commissioners shall be elected by vote of the companies, individuals, copartnerships, or associations, who shall have been assessed, and whose names shall appear on the last record of assessments (next preceding such election) for and on account of the fund in this act provided to be raised, within said districts respectively, said vote to be taken at a meeting to be held in each of said districts respectively, and on the third Monday in September of each year, such place and the time and details of such meeting to be fixed by the state oil and gas supervisor, and of which meeting at least two weeks previous notice shall have been given by letter addressed to each of said persons, corporations, copartnerships, and associations, entitled to vote as aforesaid, at his or its post-office address or principal place of business.

At said meeting each of those entitled to vote as herein provided may be represented by one person holding the written authority of such voter to act for him at such meeting.

At said meeting each voter shall be entitled to one vote for each member of the board of district oil and gas commissioners who are required to be selected for such district. In addition thereto, in each district in which five commissioners are to be elected, each voter shall be entitled, for each one hundred dollars, or fraction thereof, which said voter shall have paid in accordance with his last assessment hereunder, to cast one vote for the two commissioners who are elected for three years; and in each district in which seven commissioners are to be elected, each voter shall be entitled, for each one hundred dollars, or fraction thereof, which said voter shall have paid in accordance with his last assessment hereunder, to cast one vote for the three commissioners who are elected for three years. In all subsequent elections the qualification of voters in the election of a commissioner shall be the same as in the election of the commissioner whose successor in office is being elected.

Said meeting shall select by ballot, by a majority vote of the votes represented, the number of persons as hereinbefore specified to act as district oil and gas commissioners for such district.

In any district entitled to seven commissioners, two shall be chosen for a term of one year, two for two years, and three for three years. In any district entitled to five commissioners, one shall be chosen for a term of one year, two for two years, and two for three years.

The chairman and secretary of the meeting shall issue a written certificate to the State oil and gas supervisor, setting forth the result of such election, and the name and address of each of the persons elected at said meeting as the district oil and gas commissioners for said district and the term for which each has been elected. No person shall be eligible as a district oil and gas commissioner who is not a resident of the district for which he is elected, nor shall any person be eligible for such position who is not actually engaged in the business of oil or gas development or production, within the district.

Upon receipt of the certificate so made by the chairman and secretary of any such meeting, the state oil and gas supervisor shall issue a certificate of election to the respective persons in said certificate named as the district oil and gas commissioners for said district and for the periods of one, two, or three years from and after the first Monday in October, 1917, as shall be shown in such certificate, and until their respective successors shall have been elected.

Within thirty days after their appointment by the State oil and gas supervisor, the district oil and gas commissioners for each district shall meet at a time and place within the district to be designated by the State oil and gas supervisor, and shall thereupon select one of the number as chairman.

The deputy supervisor of the district shall be ex officio secretary of said board, and shall keep a record of its proceedings, and his office shall be the office of the commissioners.

Said commissioners shall serve without compensation, except their necessary traveling expenses. The traveling expenses of said commissioners and all actual expenses incurred by or under order of said commissioners in the hearing and determination and carrying out of orders appealed to them, shall be certified to said state supervisor, and when audited by him and by the State board of control shall be paid from said fund.

On the third Tuesday in September of each year at an hour and places in said respective districts to be fixed by the State oil and gas supervisor, and of which notices shall have been given as hereinbefore specified, the successor of each of the district oil and gas commissioners whose term of appointment shall expire that year, shall be elected and qualified in the manner and subject to the provisions hereinbefore set forth, and the term of each shall be for a period of three years from and after the first Monday in October next succeeding.

All, either, or any of the district oil and gas commissioners elected in any district may be recalled by the votes of a majority of the qualified votes of the district entitled to vote as to such commissioners respectively. In case there shall be filed in the office of the State oil and gas supervisor, a written petition, signed by not less than forty per cent of those entitled to vote as to the election of any commissioner or commissioners, asking the recall of such commissioner or commissioners, said State oil and gas supervisor shall, within ten days thereafter, order and give notice of, a special election in such district to fill the office or offices of the commissioner or commissioners named in said petition for recall; and shall cause notice to be given of said election in the manner, and for the time required for regular election, and said notice shall fix the time and place of such election.

At such election, the commissioner or commissioners named in such petition for recall shall be voted upon as though candidates for election for the unexpired portion of the term for which they, respectively, were originally elected, and any other candidate or candidates may, at the same time, be voted upon. It shall require a majority of all the qualified votes entitled to vote for such commissioners, respectively, to constitute an election. In case less than a majority of all qualified votes shall be cast for any candidate, said recall shall be deemed to have failed as to the commissioner concerning whose office such vote was taken; and in case such commissioner himself shall receive a majority of the votes, said recall shall be deemed to have failed, and in either of such cases, such commissioner shall continue to serve until the expiration of his term as though no such special election had been held. But in case any person other than such commissioner shall receive a majority of the votes for such unexpired term, then such recall shall become effective and the office of the commissioner so recalled shall be vacant and upon written certificate of such election being filed with the State oil and gas supervisor, the person so chosen and elected for such unexpired term shall become the successor of the commissioner so recalled, and a certificate of his election for such unexpired term shall be issued and transmitted to him by the State oil and gas supervisor. And like proceedings shall be had in case more than one commissioner shall be included in said petition for recall.

In all recall elections qualifications for voters and the numbers of votes which they will be entitled to cast shall be the same as they respectively were in the election of the commissioner as to whom such recall election is being held.

In case of vacancy caused by the death, resignation, or removal from district or ceasing to be engaged in the business of development or production of oil or gas in the district as to the office of any commissioner, such vacancy shall be filled until the next annual election by the State oil and gas supervisor, who

shall appoint to fill such vacancy an eligible person nominated in writing by the remaining commissioners of such district.

Upon any subject in which any commissioner is personally interested, or upon which any corporation, copartnership, association, or individual by whom he is employed is directly interested as a party, such commissioner shall not be entitled to sit or vote.

The board of commissioners shall be entitled to call upon the supervisor for advice and written report upon any matter referred to the board of commissioners, and the supervisor shall be entitled to call meetings of the commissioners at the office of the field supervisor upon five days' written notice to obtain their written advice upon any matters relating to his work within their district.

Complaint, investigation, and order.

Sec. 11. Upon receipt by the supervisor or deputy supervisor of a written complaint specifically setting forth the condition complained against, signed by a person, firm, corporation, or association owning land or operating wells within a radius of 1 mile of any well or group of wells complained against, or upon the written complaint specifically setting forth the condition complained against, signed by any one of the board of commissioners for the district in which said well or group of wells complained against is situated, the supervisor must make an investigation of said well or wells and render a written report, stating the work required to repair the damage complained of or stating that no work is required. A copy of said order must be delivered to the complainant, or if more than one each of said complainants, and if the supervisor order the damage repaired a copy of such order shall be delivered to each of the owners, operators, or agents having in charge the well or wells upon which the work is to be done. Said order shall contain a statement of the conditions sought to be remedied or repaired and a statement of the work required by the supervisor to repair such condition. Service of such copies shall be made by mailing to such persons at the post-office address given.

Testimony.

Sec. 12. In any proceeding before the board of commissioners as herein provided, or in any other proceeding or proceedings instituted by the supervisor for the purpose of enforcing or carrying out the provisions of this act, or for the purpose of holding an investigation to ascertain the condition of any well or wells complained of, or which in the opinion of the supervisor may reasonably be presumed to be improperly drilled, operated, maintained, or conducted, the supervisor and the chairman of the board of commissioners shall have the power to administer oaths and may apply to a judge of the superior court of the State of California in and for the county in which said proceedings or investigation is pending for a subpoena for witnesses to attend at said proceeding or investigation. Upon said application of said supervisor or said chairman of said board of commissioners said judge of said superior court must issue a subpoena directing said witness to attend said proceeding or investigation: *Provided, however,* That no person shall be required to attend upon such proceeding, either with or without such books, papers, documents, or accounts unless residing within the same county or within thirty miles of the place of attendance. But the supervisor or the chairman of the board of commissioners may in such case cause the deposition of witnesses residing within or without the State to be taken in the manner prescribed by law for like deposition in civil actions in superior courts of this State, and to that end may, upon application to a judge of the superior court of the county within which said proceeding or investigation is pending, obtain a subpoena compelling the attendance of wit-

nesses and the production of books, papers, and documents at such places as he may designate within the limits hereinbefore prescribed. Witnesses shall be entitled to receive the fees and mileage fixed by law in civil causes payable from the fund hereinafter created. In case of failure or neglect on the part of any person to comply with any order of the supervisor as hereinbefore provided, or any subpoena, or upon the refusal of any witness to testify to any matter regarding which he may lawfully be interrogated, or upon refusal or neglect to appear and attend at any proceeding or hearing on the day specified, after having received a written notice of not less than ten days prior to such proceeding or hearing, or upon his failure, refusal, or neglect to produce books, papers, or documents as demanded in said order or subpoena upon such day, such failure, refusal, or neglect shall constitute a misdemeanor, and each day's further failure, refusal, or neglect shall be and be deemed to be a separate and distinct offense, and it is hereby made the duty of the district attorney of the county in which said proceeding, hearing, or investigation is to be held, to prosecute all persons guilty of violating this section by continuous prosecution until such person appears or attends or produces such books, papers, or documents or complies with said subpoena or order of the supervisor or chairman of the board of commissioners.

Final decision, and order by commissioners.

SEC. 13. Within ten days after hearing the evidence the board of commissioners must make a written decision with respect to the order appealed from, and in case the same is affirmed or modified, shall retain jurisdiction thereof until such time as the work ordered to be done by such order shall be finally completed. This written decision shall be served upon the owner or his agent and shall supersede the previous order of the supervisor. In case no written decision be made by said board of commissioners within thirty days after the date of notice by the supervisor as provided in section ten hereof the order of the supervisor shall be effective and subject only to review by writ of certiorari from the superior court as provided in section fourteen hereof.

Repair of wells by supervisor—Review by superior court.

SEC. 14. On or before thirty days after the date of serving an order of the supervisor, provided for in section eight hereof, or in case of appeal to the board of commissioners on or before thirty days after date of serving the decision of the board, as provided in sections twelve and thirteen hereof, or in the event review be taken of the order of the board of commissioners within ten days after affirmance of such order, the owner shall commence in good faith the work ordered and continue until completion. If the work has not been so commenced and continued to completion, the supervisor shall appoint agents as he deems necessary who shall enter the premises and perform the work. Accurate account of such expenditures shall be kept and the amount paid from the fund hereinafter created upon the warrant of the State controller. Any amount so expended shall constitute a lien against the property upon which the work is done. The decision of the board of commissioners in such case may be reviewed by writ of certiorari from the superior court of the county in which the district is situated if taken within ten days after the service of the order upon said owner, operator, or agent of said owner or operator as herein provided, or within ten days after decision by the board of commissioners upon petitions by the supervisor. Such writ shall be made returnable not later than ten days after the issuance thereof and shall direct the district board of oil and gas commissioners to certify their record in the cause to such court. On the return day the cause shall be heard by the court unless for good cause the same be continued, but no continuance shall be

permitted for a longer period than thirty days. No new or additional evidence shall be introduced in the court before the cause shall be heard upon the record of the district board of oil and gas commissioners. The review shall not be extended further than to determine whether or not

1. The commission acted without or in excess of its jurisdiction.

2. The order, decision, or award was procured by fraud.

3. The order, decision, rule, or regulation is unreasonable.

4. The order, decision, regulation, or award is clearly unsupported by the evidence.

If no review be taken within ten days, or if taken in case the decision of the board is affirmed, the lien upon the property shall be enforced in the same manner as the other liens on real property are enforced, and shall first be enforced against the owner of the well, against the operator and against the personal property and fixtures used in the construction or operation thereof, and then if there be any deficiency against the land upon which the work is done, upon the request of the supervisor, the State controller must in the manner provided in section forty-four of this act, bring an action for the enforcement of said lien.

Casing—Water shut-off.

SEC. 15. It shall be the duty of the owner of any well now drilled, or that may be drilled in the State of California, on lands producing or reasonably presumed to contain petroleum or gas, to properly case such well or wells with metal casing, in accordance with methods approved by the supervisor, and to use every effort and endeavor in accordance with the most approved methods to effectually shut off all water overlying or underlying the oil or gas-bearing strata, and to effectually prevent any water from penetrating such oil or gas-bearing strata.

Whenever it appears to the supervisor that any water is penetrating oil or gas-bearing strata, he may order a test of water shut-off and designate a day upon which the same shall be held. Said order shall be in written form and served upon the owner of said well at least ten days prior to the day designated in said order as the day upon which said shut-off test shall be held. Upon the receipt of such order it shall be the duty of the owner to hold said test in the manner and at the time prescribed in said order.

Abandonment of well.

SEC. 16. It shall be the duty of the owner of any well referred to in this act, before abandoning the same, or before removing the rig, derrick, or other operating structure therefrom, or removing any portion of the casing therefrom, to use every effort and endeavor in accordance with methods approved by the supervisor, to shut off and exclude all water from entering oil-bearing strata encountered in the well. Before any well is abandoned the owner shall give written notice to the supervisor, or his local deputy, of his intention to abandon such well and of his intention to remove the derrick or any portion of the casing from such well and the date upon which such work of abandonment or removal shall begin. The notice shall be given to the supervisor, or his local deputy, at least five days before such proposed abandonment or removal. The owner shall furnish the supervisor, or his deputy with such information as he may request showing the condition of the well and proposed method of abandonment or removal. The supervisor, or his deputy, shall, before the proposed date of abandonment or removal, furnish the owner with a written order of approval of his proposal or a written order stating what work will be necessary before approval, to abandon or remove will be given. If the supervisor shall fail within the specified time to give the owner a written order such failure shall be considered as an approval of the owner's proposal to abandon the well, or to remove the rig or casing therefrom.

Commencement of drilling.

SEC. 17. The owner or operator of any well referred to in this act shall, before commencing the work of drilling an oil or gas well, file with the supervisor, or his local deputy, a written notice of intention to commence drilling. Such notice shall also contain the following information: (1) Statement of location and elevation above sea level of the floor of the proposed derrick and drill rig; (2) the number or other designation by which such well shall be known, which number or designation shall not be changed after filing the notice provided for in this section, without the written consent of the supervisor being obtained therefor; (3) the owner's or operator's estimate of the depth of the point at which water will be shut off, together with the method by which such shut-off is intended to be made and the size and weight of casing to be used; (4) the owner's or operators' estimate of the depth at which oil or gas-producing sand or formation will be encountered.

After the completion of any well the provisions of this section shall also apply, as far as may be, to the deepening or redrilling of any well, or any operation involving the plugging of any well or any operations permanently altering in any manner the casing of any well: *And provided further*, That the number or designation by which any well heretofore drilled has been known, shall not be changed without first obtaining a written consent of the supervisor.

Log of well—Prospect well.

SEC. 18. It shall be the duty of the owner or operator of any well referred to in this act to keep a careful and accurate log of the drilling of such well, such log to show the character and depth of the formation passed through or encountered in the drilling of such well, and particularly to show the location and depth of the water-bearing strata, together with the character of the water encountered from time to time (so far as ascertained) and to show at what point such water was shut off, if at all, and if not, to so state in such log, and show completely the amounts, kinds, and size of casing used, and show the depth at which oil-bearing strata are encountered, the depth and character of same, and whether all water overlying and underlying such oil-bearing strata was successfully and permanently shut off so as to prevent the percolation or penetration into such oil-bearing strata; such log shall be kept in the local office of the owner or operator, and together with the tour reports of said owner or operator, shall be subject, during business hours, to the inspection of the supervisor, or any of his deputies, or any of the commissioners of the district, except in the case of a prospect well as hereinafter defined. Upon the completion of any well, or upon the suspension of operations upon any well, for a period of six months if it be a prospect well, or for thirty days, if it be in proven territory, a copy of said log in duplicate, and in such form as the supervisor may direct, shall be filed within ten days after such completion, or after the expiration of said thirty-day period, with the field supervisor, and a like copy shall be filed upon the completion of any additional work in the deepening of any such well.

The State oil and gas supervisor shall determine and designate what wells are prospect wells within the meaning of this act and no reports shall be required from such prospect wells until six months after the completion thereof.

The owner or operator of any well drilled previous to the enactment of this act shall furnish to the supervisor or his deputy a complete and correct log in duplicate and in such form as the supervisor may direct, or his deputy, of such well, so far as may be possible, together with a statement of the present condition of said well.

Test of shut-off.

SEC. 19. It shall be the duty of the owner or operator of any well referred to in this act to notify the deputy supervisor of the time at which the owner or op-

erator shall test the shut-off of water in any such well. Such notice shall be given at least five days before such test. The deputy supervisor or an inspector designated by the supervisor shall be present at such test and shall render a report in writing of the result thereof to the supervisor, a duplicate of which shall be delivered to the owner. If any test shall be unsatisfactory to the supervisor he shall so notify the owner or operator in said report and shall, within five days after the completion of such test, order additional tests of such work as he deems necessary to properly shut off the water in such well and in such order shall designate a day upon which the owner or operator shall again test the shut off of water in any such well, which day may, upon the application of the owner, be changed from time to time in the discretion of the deputy supervisor.

Production reports.

SEC. 20. It shall be the duty of every person, association, or corporation producing oil in the State of California to file with the supervisor, at his request, but not oftener than once in each month, a statement showing amount of oil produced during the period indicated from each well, together with its gravity and the amount of water produced from each well, estimated in accordance with methods approved by the supervisor, and the number of days during which fluid was produced from each well, the number of wells drilling, producing, idle, or abandoned, owned or operated by said person, association, or corporation: *Provided*, That upon request and satisfactory showing a longer interval may be fixed by the State oil and gas supervisor as to such reports in the case of any specific owner or operator.

This information shall be in such form as the supervisor may designate.

Penalty.

SEC. 21. Any owner or operator of a well referred to in this act, or employee thereof, who refuses to permit the supervisor or his deputy to inspect the same, or who willfully hinders or delays the enforcement of this act, and every person, firm, or corporation who violates any provision of this act, is guilty of a misdemeanor and shall be punishable by a fine of not less than \$100 or by imprisonment in the county jail for not less than thirty days, or by both such fine and imprisonment.

Police power of the State.

SEC. 21a. The charges hereinafter provided for are directed to be levied by the State of California as necessary in the exercise of its police power and to provide a means by which to supervise and protect deposits of petroleum and gas within the State of California, in which deposits the people of the State of California are hereby declared to have a primary and supreme interest.

Charges assessed.

SEC. 22. Charges levied, assessed, and collected as hereinafter provided upon the properties of every person, firm, corporation, or association operating any well or wells for the production of petroleum in this State, or operating any well or wells for the production of natural gas in this State, which gas wells are situate on lands situate within two miles, as near as may be, of any petroleum or gas well the production of which is chargeable under this act, shall be used exclusively for the support and maintenance of the department of petroleum and gas hereinbefore created, and shall be assessed and levied by the State mineralogist and collected in the manner hereinafter provided.

Charges on oil.

SEC. 23. Every person, firm, corporation, or association operating any petroleum well or wells in this State shall annually pay a charge to the State

treasurer at a uniform rate per barrel of petroleum produced for the preceding calendar year at the time and in the manner hereinafter provided, based upon a verified report as herein provided.

Charges on gas.

SEC. 24. Every person, firm, corporation, or association operating any gas well or wells in this State shall annually pay a charge to the State treasurer based upon the amount of gas sold in the preceding calendar year, at a fixed rate per thousand cubic feet, at the times and in the manner hereinafter provided, based upon a verified report as herein provided.

Charges on land.

SEC. 25. Every person, firm, corporation, or association owning any oil land, as determined by the supervisor, shall annually pay a charge to the State treasurer at the time and in the manner hereinafter provided, which charge shall be a uniform rate per acre. Said charge shall be based upon a verified report as provided herein: *Provided, however,* That such lands so assessed shall not be called upon to pay more than one-tenth of the total charges or moneys proposed to be assessed, levied, and collected under the provisions of this act for any one year.

SEC. 26. The charges assessed, levied, and to be collected under the provisions of this act shall be in addition to any and all charges, taxes, assessments, or licenses of any kind or nature paid by or upon the properties assessed hereunder.

Annual financial estimate.

SEC. 27. The State mineralogist shall annually, on or before the first Monday in March, acting in conjunction with the State board of control, make an estimate of the amount of moneys which shall be required to carry out the provisions of this act.

At the time of making such estimate the State mineralogist shall report to the State board of control the amount of money in the petroleum and gas fund on the day such estimate is made, less the amount of money necessary for the support of the department of petroleum and gas for the remainder of the fiscal year, and the amount of such estimate shall in no event exceed the difference between the amount thus determined as remaining in the petroleum and gas fund at the end of the fiscal year and the sum of \$150,000.

Annual reports by owners.

SEC. 28. The State mineralogist shall prescribe the form and contents of all reports for making the charge or other purposes to carry out the intent and provision of this act, which form shall be mailed in duplicate to the person, firm, corporation, or association owning property or assessed under the provisions of this act.

SEC. 29. Every person, firm, corporation, or association chargeable under the provisions of this act shall, within ten days after the first Monday in March of each year, report to and file with the State mineralogist a report, in such form as said officer may prescribe, giving any and all items of information as may be demanded by said report and necessary to carry out the provisions of this act, which report shall be verified by such person or officer as the State mineralogist may designate.

SEC. 30. If any person, firm, corporation, or association chargeable under the provisions of this act shall fail or refuse to furnish the State mineralogist within the time prescribed in this act the verified report provided for in this act, the State mineralogist must note such failure or refusal in the record of assessments hereinafter in this act provided for, and must make an estimate of

the petroleum or gas production or landed area to be assessed of any such person, firm, corporation, or association, and must assess the same at the amount thus estimated and compute the charge thereon, which assessment and charge shall be the assessment and charge for such year. And if in the succeeding year any such person, firm, corporation, or association shall again fail and refuse to furnish the verified report required by this act, the State mineralogist shall make an estimate as aforesaid, which estimate shall not be less than twice the amount of the estimate made by him for the previous year, and shall note such failure or refusal as above provided, and the said estimate so made shall be the assessment or charge for said year. In case of each succeeding consecutive failure or refusal the said State mineralogist shall follow the same procedure until a true statement or report shall be furnished.

Penalty.

SEC. 31. Any person, firm, corporation, or association failing or refusing to make or furnish any report which may be required pursuant to the provisions of this act, or who wilfully renders a false or fraudulent report, shall be guilty of a misdemeanor and subject to a fine of not less than \$300 nor more than \$1,000, or by imprisonment in the county jail not exceeding six months, or both such fine and imprisonment for each such offense.

Extension date for filing reports.

SEC. 32. The State mineralogist may, for good cause shown, by order entered upon his minutes, extend for not exceeding thirty days the time fixed in this act for filing any report herein provided for.

Rate of assessment.

SEC. 33. On or before the third Monday before the first Monday in July of each year the State mineralogist shall determine the rate or rates which shall produce the sums necessary to be raised as provided in section twenty-seven of this act. Within the same time the said State mineralogist shall extend into the proper column of the record of assessments hereinafter provided for, the amount of charges due from each person, firm, corporation, or association.

SEC. 34. Between the first Monday in March and the third Monday before the first Monday in July in each year, the State mineralogist must assess and levy the charges as and in the manner provided for in this act. The assessments must be made to the person, firm, corporation, or association owning or operating the property subject to assessment hereunder on the first Monday in March. If the name of the owner is unknown to the State mineralogist, such assessment must be made to unknown owners. Clerical errors occurring or appearing in the name of any person, firm, corporation, or association whose property is properly assessed and charged, or in the making or extension of any assessment or charge upon the records which do not affect the substantial rights of the payer, shall not invalidate the assessment or charge.

Equalization.

SEC. 35. The State mineralogist and the chairman of the State board of control and the chairman of the State board of equalization shall constitute a board of review, correction, and equalization, and shall have all the powers and perform such duties as usually devolve upon a county board of equalization under the provisions of section three thousand six hundred and seventy-two of the Political Code. The State mineralogist shall act as secretary of said board and shall keep an accurate minute of the proceedings thereof. Said board of review, correction, and equalization shall meet at the State capitol on the third Monday before the first Monday in July of each year and remain in session

from day to day until the first Monday in July for the purpose of carrying out the provisions of this section.

Publication of assessment notice.

SEC. 36. On the third Monday before the first Monday in July of each year the State mineralogist shall cause to be published a notice, one or more times, in a daily, or weekly, or semiweekly newspaper of general circulation published in the counties of Fresno, Kern, Los Angeles, Orange, Ventura, and Santa Barbara and such other counties as may contain lands or produce oil or gas charged under and pursuant to the terms and provisions of this act, if one be published therein, otherwise in a newspaper of general circulation published in the county nearest to such county designated herein in which no such paper is published, that the assessment of property and levy of charges under and in pursuance of this act has been completed and that the records of assessments containing the charges due will be delivered to the State controller on the first Monday in July, and that if any person, firm, corporation, or association is dissatisfied with the assessment made or charge fixed by the State mineralogist he or it may, at any time before said first Monday in July, apply to said board of review, correction, and equalization to have the same corrected in any particular. The said board shall have the power at any time before said first Monday in July to correct the record of assessments and may increase or decrease any assessment or charge therein if in its judgment the evidence presented or obtained warrants such action. Costs of such publication in any county shall be paid from the petroleum and gas fund: *Provided, however,* That the omission to publish said notice as hereinbefore and in this section provided shall not affect the validity of any assessment levied under or pursuant to the provisions of this act.

Record of assessment.

SEC. 37. The State mineralogist must prepare each year a book in one or more volumes, to be called the "Record of assessments and charges for the petroleum and gas fund," in which must be entered, either in writing or printing, or both writing and printing, each assessment and levy or charge made by him upon the property provided to be assessed and charged under this act, describing the property assessed, and such assessments may be classified and entered in such separate parts of said record as said State mineralogist shall prescribe.

SEC. 38. On the first Monday in July the State mineralogist must deliver to the State controller the record of assessments and charges for the petroleum and gas fund, certified to by said State mineralogist, which certificate shall be substantially as follows: "I, -----, State mineralogist, do hereby certify that between the first Monday in March and the first Monday in July, 19____, I made diligent inquiry and examination to ascertain all property and persons, firms, corporations, and associations subject to assessment for the purpose of the petroleum and gas fund as required by the provisions of the act of legislature approved June 10, 1915, providing for the assessment and collection of charges for oil protection; that I have faithfully complied with all the duties imposed upon me by law; that I have not imposed any unjust or double assessment through malice or ill will or otherwise; nor allowed any person, firm, corporation, or association or property to escape a just assessment or charge through favor or regard or otherwise." But the failure to subscribe such certificate to such record of assessments and charges for oil protection, or any certificate, shall not in any manner affect the validity of any assessment or charge.

Payment of charges.

SEC. 39. The charges levied and assessed under the provisions of this act shall be due and payable on the first Monday, in July in each year, and one-half thereof shall be delinquent on the sixth Monday after the first Monday in July at six o'clock p. m. and unless paid prior thereto fifteen per cent shall be added to the amount thereof, and unless paid prior to the first Monday in February next thereafter at six o'clock p. m. an additional five per cent shall be added to the amount thereof, and the unpaid portion, or the remaining one-half of said charges, shall become delinquent on the first Monday in February next succeeding the day upon which they become due and payable, at six o'clock p. m.; and if not paid prior thereto five per cent shall be added to the amount thereof.

Publication of notice of payments due.

SEC. 40. Within ten days after the receipt of the record of assessments and charges for oil protection the State controller must begin the publication of a notice to appear daily for five days in one daily newspaper of general circulation published in each of the counties of Fresno, Kern, Los Angeles, Orange, Ventura, and Santa Barbara and such other counties as may contain lands or produce oil or gas charged under or pursuant to the terms and provisions of this act, if one be published therein; otherwise, for at least two times in a weekly or semiweekly paper of general circulation published therein, or if there be neither a daily nor weekly nor semiweekly paper of general circulation published in any one of such counties, then the publication of the notice for such county shall be made in a similar manner in a newspaper of general circulation published in the county nearest such county, specifying: (1) That he has received from the State mineralogist the record of assessments and charges for oil protection; (2) that the charges therein assessed and levied are due and payable on the first Monday in July and that one-half thereof will be delinquent on the sixth Monday after the first Monday in July at six o'clock p. m., and that unless paid to the State treasurer at the capital prior thereto, fifteen per cent will be added to the amount thereof, and unless paid prior to the first Monday in February next thereafter at six o'clock p. m. an additional five per cent will be added to the amount thereof, and that the remaining one-half of said charges will become delinquent on the first Monday in February next succeeding the day upon which they become due and payable, at six o'clock p. m., and if not paid to the State treasurer at the capital prior thereto five per cent will be added to the amount thereof. Costs of such publication in any county shall be paid from the petroleum and gas fund.

Charges become lien.

SEC. 41. The assessments and charges levied under the provisions of this act shall constitute a lien upon all the property of every kind and nature belonging to the persons, firms, corporations, and associations assessed under the provisions hereof, which lien shall attach on the first Monday in March of each year. Such lien shall be enforced and said charges collected by an action by the State controller as provided in section 44 of this act.

Charges payable to treasurer.

SEC. 42. All charges assessed and levied under the provisions of this act shall be paid to the State treasurer upon the order of the State controller. The controller must mark the date of payment of any charge on the record of assessments for the petroleum and gas fund and shall give a receipt for such payment in such form as the controller may prescribe. Errors appearing upon the face of any assessment on said records of assessments or over charges may be

corrected by the controller by and with the consent of the State board of control, in such manner and at such time as said controller and said board shall agree upon.

Protest of charges.

SEC. 43. Any person, firm, corporation, or association claiming and protesting as herein provided that the assessment made or charges assessed against him or it by the State mineralogist is void, in whole or in part, may bring an action against the State treasurer for the recovery of the whole or any part of such charges, penalties or costs paid on such assessment, upon the grounds stated in said protest, but no action may be brought later than the third Monday in February next following the day upon which the charges were due, nor unless such person, firm, corporation, or association shall have filed with the State controller at the time of payment of such charges, a written protest stating whether the whole assessment or charge is claimed to be void, or if a part only, what part, and the grounds upon which such claim is founded, and when so paid under protest the payment shall in no case be regarded as voluntary.

Whenever, under the provisions of this section, an action is commenced against the State treasurer, a copy of the complaint and of the summons must be served upon the treasurer, or his deputy. At the time the treasurer demurs or answers, he may demand that the action be tried in the superior court of the county of Sacramento, which demand must be granted. The attorney employed by the State oil and gas supervisor must defend such action: *Provided, however*, the said mineralogist may at the request of the said oil and gas supervisor employ additional counsel, the expense of which employment shall be paid from the petroleum and gas fund. The provisions of the Code of Civil Procedure relating to pleadings, proofs, trials, and appeals are applicable to the proceedings herein provided for.

A failure to be in such action within the time herein specified shall be a bar against the recovery of such charges. In any such action the court shall have the power to render judgment for the plaintiff for any part, or portion of the charge, penalties, or costs found to be void and so paid by plaintiff upon such assessment.

Delinquent charges.

SEC. 44. The State controller shall, on or before the thirtieth day of May next following the delinquency of any charge as provided in this act, bring an action in a court of competent jurisdiction, in the name of the people of the State of California, in the county in which the property assessed is situated, to collect any delinquent charges or assessments, together with any penalties or costs, which have not been paid in accordance with the provisions of this act and appearing delinquent upon the records of assessments and charges for the petroleum and gas fund in this action provided for.

The attorney for the State oil and gas supervisor shall commence and prosecute such action to final judgment and the provisions of the Code of Civil Procedure relating to service of summons, pleadings, proofs, trials, and appeals are applicable to the proceedings herein provided for. The State mineralogist may employ additional counsel to assist the attorney for the State oil and gas supervisor, and the expense of such employment shall be paid from the petroleum and gas fund.

Payments of the penalties and charges, or amount of the judgment recovered in such action must be made to the State treasurer. In such actions the record of assessment and charges for oil protection, or a copy of so much thereof as is applicable in said action, duly certified by the controller showing unpaid charges against any person, firm, corporation, or association assessed by the

State mineralogist is prima facie evidence of the assessment upon the property, the delinquency, the amount of charges, penalties, and costs due and unpaid to the State, and that the person, firm, corporation, or association is indebted to the people of the State of California in the amount of charges and penalties therein appearing unpaid and that all the forms of law in relation to the assessment of such charges have been complied with.

First assessment March, 1916.

SEC. 45. The first assessment under the provisions of this act shall be as of the first Monday in March, nineteen hundred sixteen, and the reports of petroleum production and sales of gas herein provided to be assessed shall be reported for the calendar year ending December thirty-first, nineteen hundred fifteen. The lands herein provided to be assessed and charged shall be assessed to the owners thereof as of the first Monday in March, nineteen hundred sixteen.

Disposal of funds.

SEC. 46. All the moneys heretofore paid to the State treasurer under or pursuant to the provisions of this act and deposited to the credit of the oil protection fund, shall be withdrawn from said fund, which is hereby abolished, and deposited to the credit of the petroleum and gas fund which is hereby created. All of the moneys hereafter paid to the State treasurer under or pursuant to the provisions of this act shall be deposited to the credit of the petroleum and gas fund. All moneys in such fund shall be expended under the direction of the State mineralogist, drawn from such fund for the purpose of this act upon warrants drawn by the controller of the State, upon demands made by the State mineralogist, and audited by the State board of control. Of the moneys in said petroleum and gas fund, when such action has been authorized by the State board of control, the State mining bureau may withdraw, without at the time furnishing vouchers and itemized statements, a sum not to exceed \$500, said sum so drawn to be used as a revolving fund where cash advances are necessary. At the close of each fiscal year, or at any other time, upon demand of the board of control, the moneys so drawn shall be accounted for and substantiated by vouchers and itemized statements submitted to and audited by the board of control.

SEC. 47. All moneys received in repayment of repair work done under the order and direction of the supervisor as hereinbefore provided, shall be returned and credited to the petroleum and gas fund.

Annual report by supervisor.

SEC. 48. On or before the first day of October of each and every year the supervisor shall submit a report in writing to the State mineralogist showing the total number of barrels of petroleum produced in each county in the State during the previous calendar year, together with the total cost of said department for the previous fiscal year and the net amount remaining in the petroleum and gas fund available for the succeeding fiscal year's expense, also the total amount delinquent and uncollected from any assessments or charges levied under or pursuant to the provisions of this act. Such report shall also include such other information as the supervisor may deem advisable. The State mineralogist shall make public such statements promptly after receipt of the same from the supervisor for the benefit of all parties interested therein.

Recording of leases.

SEC. 49. The owner or operator of any lands or tenements subject to assessment under this act shall, within six months after this act goes into effect, file with the supervisor a certificate which shall contain the names of all the parties

claiming an interest in or to said lands and full description of the property and the names of all parties in interest where such interest is held by lease, license, or assignment.

Definitions.

SEC. 50. Whenever the term "supervisor" is used in this act it shall be taken to mean the "State oil and gas supervisor"; the term "oil" shall include petroleum"; the term "petroleum" shall include "oil"; the term "gas" shall mean natural gas coming from the earth; the term "operator" shall mean any person, firm, or corporation drilling, maintaining, operating, pumping, or in control of a well in any territory which the supervisor determines to be oil or gas producing territory; the term "owner" shall include "operator" when any oil or gas well is operated or has been operated or is about to be operated by any person, firm, or corporation other than the owner thereof; and the term "operator" shall include "owner" when any such well is or has been or is about to be operated by or under the direction of the owner, except that all the provisions of this act relating to assessments for the purposes of this act based upon the annual production of oil or petroleum or sale of gas, as set forth in sections twenty-two to forty-five, inclusive, of this act, shall apply only to a person, firm, or corporation operating an oil or petroleum or gas well, and shall not apply to the owner of such well if some person, firm, or corporation other than such owner has been actually operating the well during the whole period for which such annual charge is made, but in the event that the actual operation of any such well changes hands during such period the charge shall be apportioned upon the basis of the oil or petroleum or gas produced, and the lien provided for in section forty-one of this act shall be a lien against the property of each and all such operators.

Appropriation first year.

SEC. 51. There is hereby appropriated out of any moneys in the State treasury not otherwise appropriated the sum of \$20,000, which said sum shall be immediately transferred by the State controller on the books of his office from the general fund to the "oil-protection fund" created by section forty-six of this act.

The above-mentioned fund shall be available for the uses of the State mineralogist for the maintenance of the department of petroleum and gas and for the necessary expenses of the controller in carrying out the provisions of this act. When the collections paid to the State treasurer, as herein provided, equal the sum of \$30,000, then said sum of \$20,000 shall be retransferred from the oil-production fund to the general fund. The moneys received into the State treasury through the provisions of this act are hereby appropriated for the uses and purposes herein specified.

Constitutionality.

SEC. 52. If any section, subsection, sentence, clause, or phrase of this act is for any reason held to be unconstitutional, such decision shall not affect the validity of the remaining portions of this act. The legislature hereby declares that it would have passed this act, and each section, subsection, sentence, clause, and phrase thereof, irrespective of the fact that any one or more other sections, subsections, sentences, clauses, or phrases be declared unconstitutional.

Incorporated cities.

SEC. 53. This act shall be liberally construed to meet its purposes, and the supervisor shall have all powers which may be necessary to carry out the purposes of this act, but the provisions of this act shall not apply to any land or wells situated within the boundaries of an incorporated city where the drilling of oil wells is prohibited.

Repeal of previous law.

SEC. 54. That certain act entitled "An act to prevent injury to oil, gas, or petroleum bearing strata or formations by the penetration or infiltration of water therein," approved March 20, 1909, together with all acts amendatory thereof and supplemental thereto and all acts in conflict herewith, are hereby repealed. Nothing herein shall be construed as affecting the provisions of the act of June 16, 1913, establishing a State mining bureau.

TO PREVENT WASTING OF NATURAL GAS.

AN ACT Prohibiting the unnecessary wasting of natural gas into the atmosphere; providing for the capping or otherwise closing of wells from which natural gas flows; and providing penalties for violating the provisions of this act.

[Approved March 25, 1911.]

The people of the State of California, represented in senate and assembly, do enact as follows:

SECTION 1. All persons, firms, corporations, and associations are hereby prohibited from willfully permitting any natural gas wastefully to escape into the atmosphere.

SEC. 2. All persons, firms, corporations, or associations digging, drilling, excavating, constructing, or owning or controlling any well from which natural gas flows shall upon the abandonment of such well, cap or otherwise close the mouth of or entrance to the same in such a manner as to prevent the unnecessary or wasteful escape into the atmosphere of such natural gas. And no person, firm, corporation, or association owning or controlling land in which such well or wells are situated shall willfully permit natural gas flowing from such well or wells wastefully or unnecessarily to escape into the atmosphere.

SEC. 3. Any person, firm, corporation, or association who shall willfully violate any of the provisions of this act shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punished by a fine of not more than \$1,000 or by imprisonment in the county jail for not more than one year, or by both such fine and imprisonment.

SEC. 4. For the purposes of this act each day during which natural gas shall be willfully allowed wastefully or unnecessarily to escape into the atmosphere shall be deemed a separate and distinct violation of this act.

SEC. 5. All acts or parts of acts in conflict herewith are hereby repealed.

SEC. 6. This act shall take effect immediately.

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BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

ABSTRACTS OF CURRENT DECISIONS
ON
MINES AND MINING

REPORTED FROM
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BY

J. W. THOMPSON



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ABSTRACT OF CURRENT DECISIONS ON MINES AND MINING, SEPTEMBER TO DECEMBER, 1917.

By J. W. THOMPSON.

MINERALS AND MINERAL LANDS.

MINERALS.

COAL AS MINERAL.

Coal is recognized as a mineral.

United States v. Beaman, 242 Federal, 876, p. 878.

ORE CONCENTRATION PROCESS—PATENT—OIL FLOTATION PROCESS.

The invention of the patent issued to Sullman, Picard & Ballot November 6, 1906 (United States Letters Patent No. 835120), is based upon the discovery of an wholly unexplained phenomenon arising from the agitation of ore pulp containing oil and air in certain proportions. This was a discovery in an art in which it was well known that the elements of oil, air, and agitation possessed certain characteristics and produced certain results. As early as 1860 a British patent first suggested the use of oil in water concentration of ores by pointing out the affinity which oils have for metallic substances in preference to gangue. Subsequently many patentees employed the known affinity of oil for metal in ore concentration processes by using oil in proportions varying from 2 per cent to 300 per cent of the ore and recovering the oil-coated metal particles by causing them to rise to the top or sink to the bottom of the pulp. In these processes the agitation was either gentle or thorough but never great, and though always employed to produce thorough oiling of the metal it was used in different degrees for the sole purpose of causing the metal particles to rise or sink. In the prior art the oil was used for its known selective affinity for metal, agitation was employed to mix the oil with the metal, and air was introduced to supplement the buoyancy of oil in raising oil-coated metal particles to the surface. To this extent had the art of oil flotation advanced when the patentee entered it, having reached the commercial stage in only two processes, representing respectively metal-flotation and metal-sinking

processes, and having reached the stage of success in none. In the line of experiments by the patentee when the proportion of oil to ore was reduced to 1.5 per cent a "float" appeared; at 1.04 per cent still more "float" appeared; at 0.32 per cent the "float" again vastly increased; at 0.1 per cent the "float" again vastly increased. It thus developed that in using oil at 0.1 per cent or even at 0.05 per cent of the ore and after violently agitating the pulp from 2½ to 10 minutes, there arose to the surface when the pulp was brought to rest, a thick froth or foam of oil-coated air bubbles carrying oil-coated metal particles to the extent of about 90 per cent of the metal content, the foam being sufficiently stable to permit removal and metal recoveries. This was a new result based upon phenomenon then unknown and still unexplained and constituted discovery and promised a change in the art of oil flotation from laboratory experiments and mill failures to commercial success. The patent referred to covering the points mentioned has been sustained by the District and the Circuit Courts of Appeals and by the Supreme Court.

Miami Copper Co. v. Mineral Separation, 244 Federal, 752, pp. 754-757.

ORE CONCENTRATION PROCESS—OIL FLOTATION—INFRINGEMENT.

The Miami Copper Co. in its process of concentrating ores by the oil flotation process used three distinct processes that were either the processes included and covered by the Sullman, Picard & Ballot patent or their fair equivalent and which were clearly an infringement of the patent, and the company can not escape liability for such infringement by taking an additional step, although such additional step if taken alone would not constitute an infringement of the Sullman, Picard & Ballot patent.

Miami Copper Co. v. Mineral Separation, 244 Federal, 752, p. 768.

ORE CONCENTRATION PROCESS—VALIDITY OF GREENWAY PATENT.

The patent issued to H. Greenway, June 9, 1914 (Letters Patent No. 1999699), is valid. The process disclosed in this patent was a substantial departure from processes of the prior art. The heating of water is a matter of large moment and the use of acids is a matter of constant and considerable expense. By wholly dispensing with both by the use of a minute quantity of hydroxy compounds, the patentee has disclosed an original and novel plan which has broadened and made more simple the agitation process of air flotation. The novelty and inventive character of Greenway's discovery is patentable.

Miami Copper Co. v. Mineral Separation, 244 Federal, 752, p. 774.

MINERAL LANDS.**OPTION TO PURCHASE—NOTICE—OPTION ABSOLUTE.**

A lease of a mine and mining property contained an option by which the lessee might purchase the property during the term. The lease provided that notice of nonpurchase could be given any time between July 6, 1915, and May 3, 1916. The lease was analogous to a sale on approval, requiring notice of disapproval by a time limited, and on failure to give the notice the sale became absolute. By the terms of the lease a written notice dated May 11, 1916, was too late, and the lessee's option agreement became absolute and binding.

Mackey Wall Plaster Co. v. United States Gypsum Co., 244 Federal, 275, p. 278.

RIGHT OF STATE TO MINERAL LANDS.

The act of July 10, 1890 (26 Stat., 222, p. 224), admitting Wyoming to the Union, expressly declares that all mineral lands shall be exempted from the grants made by the act. Mineral lands did not in any event pass to the State under either the act of July 10, 1890, or February 28, 1891 (26 Stat., 796), the latter providing that indemnity lands shall be selected from any unappropriated surveyed public lands not mineral in character.

State of Wyoming, In re, 46 Land Decisions, 34, p. 36.

HOMESTEAD ENTRY—BURDEN OF PROOF.

A homestead entry was allowed upon proper showing and satisfactory evidence of the nonmineral character of the land. Before patent a protest was filed by a mineral claimant, claiming the land under a mining location and asserting that the homestead entry was not made in good faith, and that the land is more valuable for mining than agricultural purposes. On a hearing on such protest the burden of proof is on the protestant to prove the mineral character of the land and that the land is in fact more valuable for mining than for agricultural purposes.

Gonzales v. Stewart, 46 Land Decisions, 85, p. 87.

SALE AND CONVEYANCE.**MINERAL CHARACTER—RETURN OF SURVEYOR—PRESUMPTION.**

The return of the surveyor general in connection with the survey of public land to the effect that the land is mineral or nonmineral is sufficient evidence of its character to cast the burden of proving the contrary upon the party alleging that the land is of a different character; but the opportunities of surveyors for determining the

character of land are so uncertain that this presumption is only a slight one and may be readily overcome by evidence of a higher character.

Gonzales v. Stewart, 46 Land Decisions, 85, p. 87.

SUBSEQUENT DISCOVERY OF MINERALS.

When a public land claimant has done all that the law and authoritative regulations prescribe and has obtained an equitable title to and a vested interest in the land, any subsequent discovery or disclosure of minerals does not affect or impair his rights.

State of Wyoming, In re, 46 Land Decisions, 34, p. 36.

JURISDICTION OF LAND DEPARTMENT—QUESTIONS DETERMINED.

The Land Department is charged with the duty of determining the character of land to be selected by a State, and also it must determine the date subsequent to which the mineral question is foreclosed.

State of Wyoming, In re, 46 Land Decisions, 34, p. 36.

SELECTION BY STATE—DISCOVERY OF MINERALS.

A State has no vested right or interest in an indemnity school-land selection until approval and a discovery of mineral prior to approval defeats an indemnity selection. Prior to the approval of an indemnity selection the land included therein, if mineral in character, is open to exploration and purchase under the mining laws of the United States.

State of Wyoming, In re, 46 Land Decisions, 34, p. 38.

SELECTION OF NONMINERAL LANDS BY RAILROAD COMPANY.

The act of March 2, 1899 (30 Stat., 993), authorized a railroad company to select an equal quantity of nonmineral public lands, classified as such, in lieu of lands owned within a national park by it and relinquished to the United States. The lieu selection must be land that is not of known mineral character at the date of selection and it must have been returned as nonmineral by the official surveyor at the time of the survey. Lieu lands can not be selected under this statute of which the surveyor said in his return "mining operations are now being carried on to a great extent. Mineral indications are found in nearly all parts of the township." This return does not make specific reference to the particular tract and is possibly equivocal and uncertain, but it can not be said that either through omission or by direct reference it classified the selected tract as nonmineral.

Northern Pacific R. Co., In re, 46 Land Decisions, 1.

MINERAL LANDS NOT ACQUIRED AS HOMESTEAD—AVOIDANCE OF PATENT.

Lands known at the time of their purchase from the United States to be valuable for minerals and coal are not subject to acquisition under the homestead laws, but a patent under the homestead laws for land as agricultural may not be avoided in a suit in equity on the ground that it was mineral land unless conditions were such at the time of the entry and purchase of it as to make the fact plain at that time to the entryman and others familiar with the land and its condition, that it did in fact contain mineral deposits of such quality and value and in such quantity as to render the necessary expenditures to develop, extract, and sell them profitable. If at the time of entry and patent the land was not known to be valuable for its mineral deposits, the subsequent discovery, development, exploration, or mining on the land or on lands in its vicinity will not be sufficient to justify an avoidance of the patent.

United States v. Beaman, 242 Federal, 876, p. 878.

INDIAN LANDS—ALIENATION—CONSTRUCTION OF STATUTE.

The purpose of the act of Congress of April 18, 1912 (37 Stats. at Large, 86), was not to impose restrictions upon alienation of Osage lands but to authorize the conveyance of such of the lands to which restrictions had attached, by reason of their allotment, to living members who had subsequently died, leaving surviving them Indian heirs, members of the tribe to whom certificates of competency were issued.

Fowler v. Rogers (Oklahoma), 167 Pacific, 635, p. 636.

INDIAN LANDS—RESTRICTION ON ALIENATION.

The act of Congress of June 28, 1906 (34 Stats. at Large, 539), placed no restriction on alienation by the heirs, after the death of the ancestor, an Osage Indian, of inherited lands allotted and deeded to him in his lifetime, save only the mineral interest therein reserved to the tribe, individual disposition of which is expressly inhibited.

Fowler v. Rogers (Oklahoma), 167 Pacific, 635, p. 636.

TRANSFER TO AND BY INCOMPETENT PERSON—TITLE.

A person may be disqualified from holding title to coal lands himself, but he is a proper conduit through whom to pass title from one who has it to one who may legally take it. A corporation merely, as a corporate entity, is not disqualified from acquiring or holding coal lands.

Ketchum Coal Co. v. Pleasant Valley Coal Co. (Utah), 168 Pacific, 86, p. 91.

CONVEYANCE IN TRUST—LIFE ESTATE—INHERITANCE.

A husband and wife owning royalties under and by virtue of certain coal leases conveyed the same to a trustee in trust to receive all moneys due under such leases and to pay to the husband a certain stated sum per year in quarterly installments and to pay a certain stated part of the remainder to the wife during the life of the husband, and after his death to pay her such amount as she would be entitled to receive under the intestate laws of Pennsylvania, and to pay the balance in equal shares to the three named children of the husband and wife. The intention of the husband and wife as expressed in the deed was to secure the estate to their three children in equal shares and to give up their former rights in the leases and the coal and to stipulate for certain yearly cash payments to be made to them during their lives. The conveyance was absolute during the term of the trust which was coterminous with the life of the survivor, and on the death of the wife, who survived the husband, the trust ended and the estate passed to the three children in equal shares.

Miners' Bank of Wilkes-Barre, In re (Pennsylvania), 101 Atlantic, 934.

SURFACE AND MINERALS—OWNERSHIP AND SEVERANCE.**SEPARATION OF MINERALS AND SURFACE—ADVERSE POSSESSION.**

In order to make a holding adverse to one who has reserved all mineral rights and the right to enter thereon for the purpose of extracting the minerals, there must have been some denial of his right or some assertion of a claim incident with his right which does not necessarily appear where a person uses the land merely for agricultural purposes, as such use is entirely consistent with the right of another to prospect for oil and gas under the surface. The possession of the surface by the owner for the purpose of cultivation gives him no possession of the minerals or oil and gas under the surface and does not exclude the owner of the minerals from the right to go upon the land and prospect for the same.

Barker v. Campbell-Ratliffe Land Co. (Oklahoma), 167 Pacific, 463.

ADVERSE POSSESSION OF MINERALS.

In all freehold lands an adverse claim to the mineral must be distinctly established against the owner of the surface. This result may be shown by the production of documents showing that the minerals have been conveyed, excepted, or reserved so as to have become vested in the claimant. But the fact is not established where the claimant was in neither actual or constructive possession of the surface, as he can not under such circumstances be held to have been in the constructive possession of the mineral.

Griffin v. Delaware & Hudson Co. (Pennsylvania), 101 Atlantic, 750, p. 752.

CONVEYANCE OF LAND—RESERVATION OF MINERALS VOID.

A deed to certain mineral lands recited that the grantors "do hereby grant, bargain, sell, and convey unto James J. Lewis and unto his heirs and assigns forever the following described lands." After describing the land the deed further recited: "To have and hold the same unto the said James J. Lewis and unto his heirs and assigns forever with all appurtenances thereto belonging with the privilege of working the same, and we except the manganese and lithograph claim hereby covenated with the said James J. Lewis that we will forever warrant and defend title to said lands against all lawful claim whatever." The reservation is in ambiguous language, but even if it were more definite it is irreconcilably repugnant to the granting clause of the deed and is therefore void.

Cole v. Collie (Arkansas), 198 Southwestern, 710.

RESERVATION OF MINERALS—OIL AND GAS.

A grant or reservation in general terms of all the minerals in a tract of land prima facie includes the oil and gas as well as the solid minerals, though such a grant or reservation is sometimes susceptible of an interpretation that excludes oil and gas.

Columbia Gas & Electric Co. v. Moore (West Virginia), 93 Southeastern, 1051, p. 1052.

RESERVATION OF MINERALS—ESTATE BY ENTIRETY.

A deed conveying certain land contained a reservation "saving and reserving, however, unto the said parties of the first part, and to their heirs and assignees forever, all ores and minerals on or beneath the surface of said land together with the right to enter upon said lands and to explore the same therefor and to mine the same without let or hindrance." The legal effect of such a clause in a deed is to separate the surface and mineral estates and to pass only the surface estate. Where the wife has no interest other than an inchoate right of dower in the lands conveyed by deed in which she joins with her husband, the presumption is that she joined merely for the purpose of subjecting her dower, and the intention and effect of a clause reserving the minerals in a deed executed by a husband and wife is not to create in the thing excepted any new right in the husband or wife but to preserve in each the same rights each had therein before the execution of the deed. A reservation of minerals in a deed conveying the land of the husband executed by the husband and wife, does not create an estate by entireties in the minerals so reserved.

Demerse v. Mitchell (Michigan), 164 Northwestern, 97, p. 98.

See *Demerse v. Mitchell (Michigan)*, 154 Northwestern, 22.

RESERVATION OF MINERALS—EFFECT.

Where the owner of land conveys the surface and reserves the minerals, the estates are as separate and as distinct as if the grantor had conveyed a one-half undivided interest. The mineral interest retained necessarily detracts from the value of the land to the grantee and to the extent to which it so detracts it is an interest in the land belonging to the grantor.

Northwestern Improvement Co. v. Oliver County (North Dakota), 164 Northwestern, 315, p. 318.

ENJOINING MINERAL OPERATION—PLEADING.

A bill for an injunction to prevent mining on a tract of land alleged a common source of title in the plaintiff's lessor and the defendant, and a severance of such title as to the minerals. The bill alleged that a former owner having the complete title to the land executed a deed conveying the minerals therein to a certain named person as grantee and retained the surface. It is also alleged that by subsequent conveyances the title to the minerals became vested in the lessor of the plaintiff and the title to the surface of the land was vested in the defendant. These allegations, admitted by demurrer, exclude all questions of conflict of boundaries and adverse title. As the defendant obtained title to the surface in 1914 it was impossible for him to have acquired title to the gas as distinct from the surface by adverse possession. When the gas or minerals were severed in title from the surface the possession of the surface by the grantees of the same was not possession of the minerals or gas beneath the surface.

Columbia Gas & Electric Co. v. Moore (West Virginia), 93 Southeastern, 1051, p. 1052.

SEPARATION OF MINERAL AND SURFACE ESTATES—VALUATION FOR TAXES.

The sale by a landowner of the minerals or coal underlying the land necessarily reduces the valuation of the land and the owner of the surface is entitled to have the reduced valuation shown and properly made for the purpose of taxation.

Board, etc. Sullivan County v. Riggs (Indiana Appeals), 117 Northeastern, 214, p. 215.

See *Riggs v. Board, etc., Sullivan County*, 181 Indiana, 172; 103 Northeastern, 1075.

COAL AND COAL LANDS.**ACTION TO AVOID PATENT—PROOF INSUFFICIENT.**

An action was instituted by the United States Government to avoid and vacate a patent for agricultural lands which subsequently proved to contain coal, on the ground that the patent issued under

the homestead law was procured by fraud. The evidence introduced on the part of the Government is not sufficient to maintain an action and to vacate the patent where "it goes no further than to raise an uncertainty and doubt in the mind, whether or not any one with all the knowledge of those familiar with the land, with the lands in the vicinity and with the conditions and circumstances surrounding these lands then had, would have known that the land here under consideration was valuable for its deposits of coal."

United States v. Beaman, 242 Federal, 876, p. 879.

SELECTION OF LIEU LANDS—CONCLUSIVENESS OF LAND DEPARTMENT'S FINDINGS.

A locator of land in a forest reservation relinquished the tract to the Government pursuant to the statute and selected in lieu thereof a tract of vacant land open to settlement not exceeding in area the tract relinquished. The statute limits the lieu selection to vacant, surveyed, and nonmineral public lands subject to homestead entries. Notice was given to the locator that upon his lieu selection coal crops and coal measures were found of purchasable quantity and workable quality. Upon denial of these facts and a hearing, the register and receiver recommended that the lieu selection be relieved from suspension and approved for patent. On appeal to the Land Department the Commissioner of the General Land Office confirmed the findings and conclusions of the register and receiver. No appeal being taken, patents were finally issued and delivered to the locator. The question whether the land in controversy was or was not coal land was a question of fact, and the determination of that question by the Land Department is final and conclusive on the courts. This rule must apply in the instant case, though the notice of the hearing was defective, where it appears that there was an actual contest and the proof was not limited to the date of the lieu selection, but was in fact extended to the date of the actual hearing before the register and receiver.

United States v. Whitted, 245 Federal, 629.

PATENT UNDER HOMESTEAD LAW—BONA FIDE PURCHASER.

Title to lands containing a valuable deposit of coal was obtained in 1902 and 1903 by the patentee under the homestead law. A coal company that purchased the land four years later, paying a valuable consideration therefor, in reliance upon the patent and without notice of any fraud in its procurement, has an equity far superior to that of the Government where for two years and more, with knowledge that the land was valuable for coal, and before the purchase by the coal company, it had instituted no suit and made no effort to invalidate the patent.

United States v. Beaman, 242 Federal, 876, p. 880.

LAND ENTERED BY ONE FOR ANOTHER—TITLE AND CONVEYANCE.

The United States statutes expressly forbid one person for himself or any company or corporation to procure directly or indirectly another person to settle upon any lands open to settlement with intent thereafter to acquire title thereto; and any title thus acquired shall be void. But section 5025 (5 U. S. Comp. Stats., 1916), has no application to a case where a patent for land was lawfully acquired and conveyance made to a person disqualified from holding it.

Ketchum Coal Co. v. Pleasant Valley Coal Co. (Utah), 168 Pacific, 86, p. 91.

CONVEYANCE—SUBSEQUENT TITLE INURES TO GRANTEE.

The statute of Utah provides that if any person, purporting to convey land in fee simple absolute, who shall not at the time have the legal estate to such land, but shall thereafter acquire the same, the legal estate so acquired shall immediately pass to the grantee, and the conveyance shall be as valid as if the legal estate had been in the grantor at the time of the conveyance. (Compiled Laws of Utah, 1907, sec. 1979.) This act applies to a person who conveyed coal lands before he had made application to purchase and before he had a right to and had acquired the title thereto from the Government and when he subsequently acquired the title from the Government it passed to his grantee.

Ketchum Coal Co. v. Pleasant Valley Coal Co. (Utah), 168 Pacific, 86, p. 91.

TITLE—CONSTRUCTIVE POSSESSION—ADVERSE POSSESSION.

In a suit in ejectment and containing also a bill to remove a cloud by which it was sought to establish the title to coal underlying a certain tract of land the complainant claimed title to the whole of the tract. The defendant owned another tract and had and held possession for over 30 years of a strip which theoretically was a part of the tract claimed by the plaintiff by constructive possession. Such claimed constructive possession of the tract or strip by the plaintiff did not create a conflicting possession and thereby defeat the defendant's title under the statute of Tennessee (Shannon's Code, sec. 4456), under which adverse possession under a deed for more than seven years gives an indefeasible title.

Glen Mary Coal & Coke Co. v. Wolfe, 243 Federal, 131, p. 135.

REMOVAL OF MINERALS—INJUNCTION—ESTOPPEL.

A trustee of an insane cotenant of coal lands can not be permitted to enjoin the lessee, one of the cotenants, from mining and removing the coal and recover from such cotenant his part of the value of the coal so removed on the ground that the insane cotenant had not

joined in the lease, where it appeared that the trustee of the insane cotenant had received and accepted his full share of rents and royalties and had used it for the benefit of his insane ward.

Wilmer v. Philadelphia-Reading Coal & Iron Co. (Maryland), 101 Atlantic, 538, p. 540.

OWNERSHIP OF COAL—RIGHT TO MAINTAIN ACTION FOR TRESPASS.

A person who has never been in the actual possession of the surface of land and who has had neither actual nor constructive possession of the coal underlying such land can not maintain an action for trespass against one who mined and removed the coal.

Griffin v. Delaware & Hudson Co. (Pennsylvania), 101 Atlantic, 750, p. 752.

TIMBER FOR MINING PURPOSES—CONTRACT OF SALE—TITLE—RESCISSION.

A mining company by deed sold all the standing timber upon its coal lands, the same to be cut and removed from the lands on or before a stated date. By a subsequent agreement between the parties the timber was estimated to contain 8,000,000 feet log scale; but if by actual measurement there was found to be a less quantity a deduction should be made in the price at a stated price per thousand feet. Prior to the date of the sale of the timber the mining company executed a mortgage on all of its mining property to secure certain bonds. This mortgage included also all the timber necessary for the development, working, and mining of the coal and the preparation of the same for market and the removal of the same. The purchaser of the timber can not rescind the contract of purchase either on the ground of false representation as to the quantity of the timber, or on the ground that the title to the timber was not then in the coal company because of the mortgage previously executed.

Hitt Lumber Co. v. Cullman Coal & Coke Co. (Alabama), 76 Southern, 347.

SALE OF COAL—PURCHASER FOR VALUE.

The fact that a purchaser paid only \$125 for the coal and minerals underlying a tract of 1,000 acres of land is not sufficient of itself to prove that a purchaser was not a purchaser for value, simply because the land titles in the vicinity were uncertain, where it appeared that the land owner himself had paid but \$125 for the land with the coal included. A purchaser to entitle him to the possession and the protection of a purchaser for value is not required to pay a consideration that is either fair or adequate but simply that the purchase is for value.

Steinman v. Clinchfield Coal Corp. (Virginia), 93 Southeastern, 684, p. 690.

BREACH OF CONTRACT FOR SALE OF COAL—MEASURE OF DAMAGES.

A coal mining company brought suit against a purchasing company to recover a balance due on account for coal sold and delivered to the purchasing company. The purchasing company by way of counterclaim alleged that the mining company had failed to deliver to it coal pursuant to its contract, and that because of such failure it was compelled to purchase coal elsewhere to fill contracts with its customers, by reason of which it sustained damages in a large sum. The coal purchased by the purchasing company was for the purpose of resale on the market of the city of Louisville, a considerable distance from the mines of the coal mining company, which fact was known to the mining company. In such case on the failure of the coal mining company to furnish coal under its contract, the damages to which the purchasing company was entitled was the difference between the contract price at the time and place of delivery, according to the contract, and the market price at that time, at such place, to be credited by the cost of transportation from the mines of the mining company to the city of Louisville; and the damages to which the purchasing company was entitled for the failure on the part of the mining company to deliver the coal, to the extent that the purchasing company, after reasonably diligent efforts to purchase other coal of similar kind and character to supply the place of that which it failed to receive from the mining company and was not able to buy other coal instead, was the profits which the purchasing company would have realized by a resale of such coal, if at the time of the making of the contract the resale of the coal and the profits to be made therefrom were within the contemplation of the parties, and if these were the inducements for the purchase of the coal.

Log Mountain Coal Co. v. White Oak Coal Co. (Kentucky), 197 Southwestern, 659, p. 661.

CONTRACT FOR SALE OF COAL—SPECIFIC PERFORMANCE.

By the terms of a contract between a coal mining company and a purchasing company, the mining company agreed to sell to the purchasing company all its output or straight mine-run coal up to 100 tons daily average for each working day of 20 days per month for one year, loaded on freight cars, for a price of \$1.50 per ton loaded on the cars. The coal was to be merchantable and of standard quality and preparation. The contract clearly contemplates a continued daily operation of the mine, requiring special knowledge, skill, and direction running over a period of 12 months. It not only requires the delivery of the output of the mine up to 100 tons daily average for 20 working days in a month, but that such coal shall be of a certain specified quality. The contract stipulates for a succession of acts and requires protracted supervision and oversight, with the exercise

of such knowledge or judgment in such oversight, and such contracts are not as a rule specifically enforced.

Black Diamond Coal Min. Co. v. Jones Coal Co. (Alabama), 76 Southern, 42, p. 43.

OIL AND OIL LANDS.

OIL AND GAS AS MINERALS.

Oil and gas are minerals within the meaning of a reservation in a deed "of all mineral rights" upon the land described in the deed.

Barker v. Campbell-Ratcliffe Land Co. (Oklahoma), 167 Pacific, 468.

CLASSIFICATION AND SELECTION—BURDEN OF PROOF.

Where land has been withdrawn or classified upon data indicating that it is mineral in character and the Government continues to assert that it does in fact contain valuable mineral deposits, an applicant who seeks to have such land declared to be nonmineral must sustain the burden of proof at a hearing had for the determination of that question. Where land was entered before the date of the withdrawal act of June 25, 1910 (36 Stat., 847), and where there is no evidence that at the date of final proof and payment the land was mineral in character and where it has been reported by Government officials as being nonmineral, the entryman will be entitled to patent, although the land is within the boundaries specified in a withdrawal order.

Hildreth, In re 46 Land Decisions, 17.

Rankine, In re 46 Land Decisions, 46.

WASTE—INJUNCTION.

The abstraction of oil from lands by one joint owner to the exclusion of his cotenant is waste, and may be enjoined by the coowner so excluded.

Paxton v. Benedum-Trees Oil Co. (West Virginia), 94 Southeastern, 472, p. 474.

RESERVATION OF MINERAL—CONSTRUCTION OF DEED.

A deed for certain described land with full covenants of warranty contained a reservation as follows: "It is hereby agreed that the parties of the first part reserve all mineral rights upon the above-described lands, and the right to enter thereon and to use so much of the surface as may be reasonable for the purpose of extracting the mineral therefrom at any time is reserved from this grant." The exception or reservation of all mineral rights is not repugnant to the covenants of title. A lessee of the mineral rights under this reservation has the right, as against a grantee of the original grantor in whose favor the reservation was made, to enter upon the land and explore and develop it for minerals.

Barker v. Campbell-Ratcliffe Land Co. (Oklahoma), 167 Pacific, 468.

AGRICULTURAL ENTRY WITHIN PETROLEUM RESERVE—RIGHTS OF ENTRYMAN.

Lands entered as agricultural were prior to final proof included within the boundaries of a petroleum reserve. In such case the entryman may apply for a restricted patent, or he may apply for a classification of the land as nonmineral, or he may apply for a hearing, or he may suffer cancellation of his entry. A classification would involve the determination of the present character of the land. An application for a hearing would involve the question as to the known oil or nonoil character of the land at the date of the submission of final proof. The withdrawal is *prima facie* evidence that the land was known to be oil in character at the time of filing final proof. In such case the burden of proof is upon the entryman to establish that the land was not known to be oil in character at the time of final proof.

Rankine, In re 46 Land Decisions, 46, p. 50.

ADVERSE POSSESSION—CLAIM OF RIGHT.

Adverse possession of oil and gas lands within the statute of Texas is an actual and visible appropriation of the land commenced and continued under a claim of right inconsistent with and hostile to the claim of another. The "claim of right" to which the statute refers means that the entry of the limitation claimant must be within the intent to claim the land as his own and to hold it for himself. It is necessary that his entry upon or holding of the land be founded upon his having some character of title as opposed to the theory of 10 years limitation statute.

Houston Oil Co. v. Jones (Texas), 198 Southwestern, 290.

OWNERSHIP OF RIVER BED—LESSEE OF OWNER PROTECTED.

In an action between the United States as the representative of the Creek Nation and the State of Oklahoma and its lessee as to the ownership of the bed of a river and the right to take oil therefrom, by agreement the lessee was permitted to continue operations and a receiver was appointed to collect and hold the royalties for the benefit of the successful party. The lessee of the Indian owner of the land on the bank of the river intervened and asked protection and a temporary injunction on the ground that the title of its lessor extended to the thread of the stream, and was neither in the Creek Nation nor the State, as the stream was not navigable. Under such a showing the lessee of the Indian allottee was entitled to protection, and it was error to refuse a temporary injunction or other proper remedy.

Producers' Oil Co. v. United States, 245 Federal, 651.

GRANT OF ROYALTIES ON OIL AND GAS—LEGAL EFFECT.

A deed by the owner of land conveyed to the grantee one-sixteenth of all the oil and one-half of all the gas within and underlying the land described, including in the conveyance one-half of all the royalties, incomes, and rentals that may arise therefrom or accrue upon the real estate described by virtue of any oil and gas lease or lease now on said described lands or which may hereafter be placed on said lands. The grant of the "royalties, incomes, and rentals" arising from the production of the oil from the land described is a grant of the oil in such land.

Paxton v. Benedum-Trees Oil Co. (West Virginia), 94 Southeastern, 472, p. 475.

NATURAL GAS.

PUBLIC UTILITY—INTEREST OF STATE.

Natural gas is a public utility in which the State is intensely interested; and this interest has been manifested in Oklahoma in several legislative enactments and it is now the established policy of that State to conserve natural gas, as evidenced by what is known as the gas conservation act (Session Laws, 1915, ch. 197).

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1064.

REGULATION OF RATES.

In fixing the rates for the use of natural gas, the value of the property is one of the important elements. In fixing the valuation of the property of a public utilities corporation, it can not be assumed that at the expiration of the life of the corporation as fixed by a statute or by its articles of incorporation, its physical property, consisting of valuable improvements, will immediately become worthless junk. In determining a proper rate, the good will should not enter into the valuation of a public utility. Where the evidence is conflicting or doubtful, there should be no allowance for what is termed "going value." In determining whether a rate fixed for the use of natural gas is reasonable, the element of supply of gas must be considered, and this may properly be based upon the experience in the past years and not on the uncertainties of further development and production. This element necessarily includes the life of the fields from which the gas is obtained, to be determined by the testimony of experienced persons. The matter of the cost of gas, whether purchased from other companies or produced by the operations of the distributing company must be considered as an element in determining rates. An allowance for depreciation or amortization must be made. Considering these matters and others, it was determined that a flat rate of 28 cents per thousand feet, fixed by

the Public Utilities Commission of Kansas was not compensatory but was unreasonably low and confiscatory, and violative of the Constitution of the United States.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658, p. 669-679.
St. Joseph Gas Co. v. Barker, 243 Federal, 206, p. 212.

PUBLIC SERVICE COMMISSION—REGULATION OF RATES.

The order of the corporation commission establishing rates for natural gas to be charged consumers in a municipality by a natural gas company, and requiring the installation of meters, is a valid order under section 593 (Session Laws, 1913, ch. 93). The power to regulate the charges for public services by municipal corporations was intended by the framers of the Constitution to be exercised by the sovereign power only. Such power is inherent in the State and is a necessary attribute to sovereignty. The legislature had the right to legislate on this subject whenever in its judgment the public good required such action. The power delegated to a municipality to regulate charges for natural gas under section 593 was such a grant of power as could be taken away by the legislature and conferred upon the corporation commission, as was done by chapter 93, Session Laws, 1913.

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1061.

REGULATION OF RATES.

The Public Utilities Commission of Ohio is not authorized by statute summarily to fix a rate to be charged consumers of natural gas, subsequent to the expiration of a contract between the gas company and a municipality served during the period within which the operation of a new ordinance prescribing such rate is suspended by reason of the filing of the referendum petition. In such case the rate should be established in accordance with the provisions of the code.

City of Cincinnati v. Public Utilities Commission of Ohio (Ohio), 117 Northeastern 381, p. 382.

REGULATION OF RATES—VALIDITY OF STATUTE.

The statute of Oklahoma of April 2, 1915 (Session Laws, 1915, p. 407), known as the meter act, is not repugnant to or in conflict with the act conferring jurisdiction upon the corporation commission (Laws, 1913, p. 150), but is supplementary thereto. The act conferring jurisdiction upon the corporation commission to fix the charges for natural gas gave the commission authority to proceed to establish rates when it saw fit, but the act did not compel action on the part of the commission. Whether the corporation commission established rates or not by the terms of the act of April 28, 1913,

requiring the installation of meters, all persons, firms, or corporations furnishing natural gas to consumers in the municipalities therein specified were required so to do and to charge at meter rates. This act did not attempt to fix the rates and the act of April 2, 1915, also known as the meter act, was to the same effect, except that it was not applicable to certain franchises and in the absence of an order from the corporation commission fixing the rates and requiring the installation of meters, the persons, firms or corporations furnishing gas in cities having such franchises were not required to do so by virtue of the terms of the meter act. But persons or corporations furnishing natural gas in the cities mentioned were not required to install meters and charge for gas at meter rates by legislative enactment, but they were not excused from doing so if the corporation commission so ordered under the authority delegated to it by the act conferring jurisdiction on the commission.

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1063.

REGULATIONS OF RATES—POWER OF CORPORATION COMMISSION.

What are known as the meter acts in Oklahoma (acts of Apr. 28, 1913, and of Apr. 2, 1915), were not applicable to towns having a population of less than 500, and the corporation commission by virtue of the authority conferred upon it by the act of March 25, 1913 (Laws, 1913, p. 150), had authority to regulate the rates for natural gas and require the installation of meters in towns of less than 500. By virtue of the proviso in the meter act of April 2, 1915 (Laws, 1915, p. 407), in addition to the persons, firms or corporations furnishing natural gas in towns having a population under 500 not being required to install meters, persons or corporations furnishing gas in cities having a population of more than 500 under the act of April 28, 1913, were also not required to install meters and to charge at meter rates; but the proviso goes no further and does not confer any greater right. It places a municipality of over 500 population that had previously granted a franchise to a natural gas company in the same situation as are towns with a population under 500. Accordingly there is nothing in either of the meter acts to prevent the corporation commission from exercising the power delegated to it by the act of April 28, 1913.

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1063.

CHANGE IN RATES—APPLICATION OF STATUTE.

The provision in the act of April 2, 1915 (Laws Oklahoma, 1915, p. 407), to the effect "that this act shall not abrogate any existing contract, or affect or change the terms or conditions of any franchises granted by any municipal corporation prior to and in effect

April 28, 1913," merely qualifies the direct legislative mandate of that act to the persons, firms, or corporations furnishing natural gas in municipalities having a population of over 500 through standard meters at meter rates, and does not affect the power of the corporation commission, under the provisions of the act of March 25, 1913 (Laws Oklahoma, 1913, p. 150), to establish rates not inconsistent with the legislative mandate of the act of 1915. By the terms of the proviso in the act of April 2, 1915, the act does not apply to contracts and franchises granted by municipal corporations prior to and in effect April 28, 1913, where the installation of such meters and the charging at meter rates would abrogate the contract or affect or change the terms or conditions of the franchises. Any such franchise granted by a municipality and in effect on that date could not be affected by the meter act.

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1063.

REGULATIONS—APPLICATION OF CONSTITUTION.

Section 18, article 9, of the constitution of Oklahoma has no application to a public service corporation furnishing natural gas to the inhabitants of a municipality and such a corporation does not come within the terms of the proviso of that section. Section 7, article 18, of the constitution prohibits the surrender of the power to regulate charges for public services and is a limitation upon the supreme legislative power as well as upon municipalities to which the power may be delegated within constitutional limitations by the legislature and simply means that this power of sovereignty can not be surrendered.

City of Pawhuska v. Pawhuska Oil & Gas Co. (Oklahoma), 166 Pacific, 1058, p. 1063.

CONTROL OF RATES—INJUNCTION.

A State court of Kansas appointed a receiver for the Kansas Natural Gas Co., with directions to operate the franchises of the corporation and to charge the rates as fixed by the public utilities commission. On application by proper parties a Federal court enjoined the receiver from enforcing the rates fixed by the utilities commission and the rates fixed by the statute of 1911 as being confiscatory in their nature. On this being done by a Federal court it was proper for the State court, having jurisdiction of the case and of the receiver, and upon application of the latter to fix a temporary rate to be charged by the receiver pending further action in the Federal court. The order of the State court fixing the temporary rates to be charged by its receiver in no wise affected the jurisdiction or the power of the Federal court to proceed to the final determination of the cause pending therein.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658, p. 666.

St. Joseph Gas Co. v. Barker, 243 Federal 206, p. 212.

PRODUCING AND DISTRIBUTING COMPANY—CONTRACTS—REASONABLE CHARGES.

A contract was entered into between two natural gas companies by which one, a producing company, should furnish natural gas to the other, a distributing company, at a specified rate and the distributing company was to sell and distribute such gas at a specified rate. The price of the producing company was to be raised or lowered in the event the distributing company received more or less than the stipulated price for the gas. Notwithstanding this contract between the companies reasonable charges only will be allowed as against the public. In a proceeding by the distributing company to enjoin compliance with an order of the Public Service Commission of Missouri restraining the distributing company from raising the rates of the gas purchased and distributed by it, the evidence was sufficient to show that the rate fixed as a reasonable rate at which the distributing company should obtain its supply of natural gas was erroneous and the producing company was entitled to a rate equal or nearly so to that fixed by the contract between the companies. The contract price as agreed upon is *prima facie* evidence of the reasonable value of the gas.

St. Joseph Gas Co. v. Barker, 243 Federal, 206, p. 212.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658.

RIGHT TO INJUNCTION.

An owner of gas in a tract of land, or his lessee, whose title is so clear as a matter of law as to preclude the necessity of resort to a jury trial for its determination may enjoin the extraction of such gas by one who has no right thereto. If the bill for injunction alleges title in the complainant it need not allege the pendency of an action at law to try the question of title nor an intention on the part of the complainant to institute such an action.

Columbia Gas & Electric Co. v. Moore (West Virginia), 93 Southeastern, 1051, p. 1052.

EMINENT DOMAIN.

POWER TO EXERCISE.

The statute of Alabama (Code, sec. 3485) provides that mining and other companies may acquire land for ways and rights of way for railways, tramways, and roads to connect any part of their lands or works with any public road, railroad, or with their mines on other lands. The use of the word "companies" in the statute can not be attributed to a purpose to subject the rights of way therein described to condemnation by individuals or firms. To construe this section of the statute as permitting individuals to condemn the rights of way described would result in reading into the act provisions not apprehended in its title which has the effect to confine the act's provisions to matters of legislation referable alone to corporations. An unincorporated partnership is not therefore authorized to exercise this power of eminent domain.

Sloss-Sheffield Steel & Iron Co. v. O'Rear (Alabama), 76 Southern, 57.

DELEGATION OF THE POWER.

A legislature strictly speaking can not delegate the power of eminent domain. It can not divest itself of sovereign powers but it can select such agencies as it chooses and confer upon them the right to take property subject to the limitations of the constitution. The right may be conferred upon corporations, public or private, upon individuals, upon foreign corporations, or consolidated company composed in part of a foreign corporation, and upon the Federal Government. In the absence of special constitutional restrictions it is solely for the legislature to judge what persons, corporations, or other agencies may be properly clothed with this power. But when the legislature clothes corporations of a certain named class only with the power, it can not be exercised by an unincorporated partnership.

Sloss-Sheffield Steel & Iron Co. v. O'Rear (Alabama), 76 Southern, 57, p. 58.

CONSTRUCTION OF STATUTE.

Section 3860 of the Code of Alabama, relating to the delegation of the right of eminent domain, does not undertake to grant the right to condemn, but only purports to describe the mode, the place, and method of proceeding where the right to condemn has been in fact conferred or delegated.

Sloss-Sheffield Steel & Iron Co. v. O'Rear (Alabama), 76 Southern, 57, p. 58.

RIGHT TO CONDEMN RAILROAD RIGHT OF WAY FOR TIPPLE SITE.

The statute of Utah authorizes a coal company to condemn lands for a tipple site but it does not authorize a coal company to condemn any portion of a right of way used for railroad purposes for a tipple site. The statute makes all rights of way for any and all purposes subject to be connected with, crossed, or intersected by any other right of way or improvement and subject to a limited use in common with the owners thereof when necessary. The statute thus limits the interference with rights of way to crossings, intersections, and connections. There is nothing in the statute conferring the right upon any person, natural or artificial, to condemn a right of way which is devoted to a quasi-public use by a common carrier for a purpose other than a similar purpose. It gives a coal company no authority to appropriate a longitudinal strip of a right of way approximately 1,000 feet in length by 80 feet in width for the purpose of erecting permanent structures thereon to be used exclusively in the coal company's business of screening, grading, handling, and loading coal which it seeks to place on the market for sale.

Ketchum Coal Co. v. Pleasant Valley Coal Co. (Utah), 168 Pacific, 86, p. 93.

ESTABLISHMENT OF HIGHWAY—LAND OF COAL COMPANY.

Under the statute of California a county may appropriate on payment of just compensation the land of a coal company for a road, and the road when established is a public road, regardless of the number of persons using it.

Riverside County v. Alberhill Coal & Clay Co. (California Appeals), 168 Pacific, 152, p. 153.

MINING TERMS.

BOTTOM BOSS.

The person who has under his direction the men who work on the bottom.

Daly v. New Stauton Coal Co. (Illinois), 117 Northeastern, 413, p. 415.

DRUMMY.

A term applied to loose coal or rock in a mine that produces a hollow sound when tapped with any hard substance.

Dodd v. Pocahontas Consol. Collieries Co., 244 Federal, 151.

GOBBING SLATE.

Gobbing slate is a term applied where a layer of slate is found between two veins of coal and the lower vein is mined out and the upper vein and the slate are shot down, the coal loaded out and then the slate moved to one side out of the way.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 Southwestern, 633.

MINER'S WEIGHT.

Miner's weight used in a coal mining lease is the basis for a price per ton to be paid for mining and is a varying quantity of mine-run material and is such quantity of material as operators and miners may agree upon as necessary or sufficient to produce a ton of prepared coal.

Drake v. Berry (Pennsylvania), 102 Atlantic, 315, p. 320.

PARTING SLATE.

Parting slate is a term applied to a thin or varying layer of slate between two seams of coal.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 Southwestern, 633.

SLUE.

Slue is a term used by miners meaning to straighten a coal cutting machine. In cutting coal the machine moves from right to left and the back part of the machine moves faster than the front and it is necessary at intervals to stop the machine and straighten it or "slue" it, as called by miners.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 562.

MINING CORPORATIONS.

BOOKS AND RECORDS—PLACE OF KEEPING—INSPECTION.

The statute of Oregon requires a mining corporation, organized under the laws of that State, to keep its books and records within the State for inspection. Where the books and records of a mining corporation have been by the corporation, the directors and others controlling the corporation, wrongfully removed from the State, a court, in a proper action, may by mandatory injunction, compel the corporation to return the books and records to the State of its residence and keep there for inspection.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 976.

AUTHORITY OF PRESIDENT.

The president of a mining corporation who by its by-laws was the general executive officer of the corporation and given general charge of the business affairs of the corporation, but having no power to incur any debt in excess of \$500, has authority to employ counsel to represent the corporation in pending litigation and to bind the corporation, and the employment of counsel was not rendered invalid because the president agreed to pay him more than \$500.

Blue Goose Min. Co. v. Northern Light Min. Co., 245 Federal, 727, p. 731.

AUTHORITY OF PRESIDENT—SPECIFIC DUTIES.

The president of a mining corporation on suggesting that the acquisition of transportation facilities would make the operation of the mine more profitable, was authorized to investigate and make a detailed report of the feasibility of the enterprise to the directors. In conducting the investigation he employed a third person to procure rights of way, obtain subscriptions, organize a corporation for the building of an electric road from the mine to the place suggested and designated. The person employed proceeded no further than the organization of a corporation looking to the construction of the road. The corporation paid all the costs and expenses of the undertaking except the services rendered by the person so employed by the president. As the president was authorized to employ such third person, the corporation could not successfully defend an action by him on the ground that it had no power to construct the road in question.

Quick Silver Min. Co. v. Anderson, 245 Federal, 67, p. 75.

LIABILITY OF CORPORATION FOR SALARY OF OFFICER.

A director of a mining corporation operating in Utah was employed as its general manager by the general officers residing in the State of Pennsylvania. He was to receive a stated monthly salary, but the mining operations ceased to be profitable and money was advanced by the other directors and officers. A monthly deduction from the salary was then agreed upon. Subsequently the salary was reduced and the general manager refusing to accept the reduced salary demanded the "back salary" and brought suit to recover the same. The agreement among the parties is sufficient to show that the back salary was not to be exacted until sufficient ore had been mined to pay the interest on the indebtedness and to meet the current expenses of the company, and where the manager expressed his confidence in the outcome of the property, the corporation can not be held liable for such back salary unless and until it can be paid from the proceeds of the property.

Dunyon v. Scranton Min. & Smelting Co. (Utah), 168 Pacific, 755.

FRAUD OF PROMOTERS—LIABILITY FOR SECRET PROFITS—PARTIES.

Three promoters of an oil company falsely represented to their associates that certain desirable property could be acquired for \$25,000 and no less, and thereby induced their associates to consent to the purchase of the property. For that purpose they subscribed and paid for shares of the capital stock of the corporation to be issued to them and authorized the payment of the money for the property. The three promoters by a secret agreement with the vendor of the property acquired the same for the corporation at an actual outlay of \$10,000 of the corporate funds paid out of the amounts so subscribed and paid to the capital stock. In an action against the fraudulent promoters to recover the secret profits obtained by them, the corporation is the proper party plaintiff.

Jarvis v. Great Bend Oil Co. (Oklahoma), 168 Pacific, 450, p. 454.

CONSPIRACY—OFFICERS AND STOCKHOLDERS—REORGANIZATION.

Where a mining corporation had purchased a mining claim, the consideration to be paid in installments out of the proceeds of the mine, and where the mining operations were not successful and the proceeds were not sufficient to make the payments and the corporation became indebted to officers and stockholders who loaned and advanced money to make payments on the claim, the fact that the creditors, stockholders, and officers acquired title to the mine and entered into a reorganization plan with other creditors of the company does not establish a conspiracy to ruin the corporation.

Munro v. Smith, 243 Federal, 654, p. 663.

DUTIES OF DIRECTORS—RIGHT TO SUE.

The mere fact that directors of a mining corporation were elected by a vote of a stockholder against whom a suit should be brought does not raise a presumption that they will refuse to order a suit brought or will conduct such suit collusively. Under the statute directors are sworn to "faithfully and honestly discharge" the duties of their trust. The presumption is that the directors of a corporation will do their duty. If an individual stockholder would excuse his failure to make a demand on the directors to bring a suit, he must name the directors and show that they themselves are the guilty parties, or show such relationship to the guilty parties by blood, marriage, or business association or such other facts as would justify the conclusion that they will refuse to do their duty. A general allegation that the corporation or its board of directors is in control of the guilty party is not sufficient.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 971.

SALE OF ASSETS TO ANOTHER CORPORATION.

The statute of Montana (sec. 4409, R. S. Codes), provides that a sale may be made of all the assets of a mining corporation only when at least two-thirds of the whole number of shares of the capital stock outstanding shall at a meeting called as provided vote and direct such sale. The statute also provides that such a sale of the assets shall work a dissolution of the corporation. The statute also gives a remedy to any stockholder not consenting to the sale by which he may have his stock appraised and receive the value thereof. A stockholder objecting to such a sale and making an application to have his stock appraised according to the provisions of the statute can not challenge the constitutionality of the statute when he is seeking relief by virtue of the provisions of the statute.

Wall v. Parrot Silver & Copper Co., 244 U. S., 407, p. 409.

Woodruff v. Producers' Oil Co., 142 Louisiana, —; 76 Southern, 803, p. 804.

ASSESSMENT—SALE OF STOCK.

Sales of stock on assessments in the nature of calls on unpaid subscriptions to the capital stock of mining corporations are authorized by statute though sales on other forms of assessments are not. As the statute does authorize such sales it will be presumed on appeal in aid of a judgment that a sale was made on a form of assessment which it could be lawfully made.

Mitchell v. Blue Star Min. Co. (Washington), 167 Pacific, 130, p. 131.

SALE OF STOCK—PLACE OF SALE.

The statute of Washington prohibits the sale of stock of a mining corporation on assessments "at the office of the company" (Remington's Code, 1915, sec. 3694). The purpose of this provision is to

secure publicity in the sales of corporate stock and to prevent sales, behind closed doors or private offices. The word "at" often has the significance of "near" and it frequently means "in." But it should be interpreted both with reference to the context where used and with reference to the object sought to be attained. This statute requires public sales where all persons may feel free to attend and where the sale may be conducted in the public view, but these conditions are not readily obtainable in a private office. The legislature by this statute only intended to prohibit sales of corporate stock for nonpayment of assessments within the office of the company and a sale of such stock on a street by a licensed auctioneer in front of one of the doors to the building in which the company had its office is not a violation of the statute.

Mitchell v. Blue Star Min. Co. (Washington), 167 Pacific, 130, p. 131.

SALE OF STOCK—VALIDITY—PLACE NOT FIXED BY BY-LAWS.

The statute of Washington (Remington Code, 1915, sec. 3694) prohibits the sale of forfeited stock of a mining corporation at the office of the company. The statute does not expressly or impliedly provide in enumerating necessary conditions attending such sales that the place of sale shall be named or fixed in the by-laws. The statute does require that notice of such sales be published, and contemplates that the notice shall name both place and time, as these are two of the essential features necessary to be included in due notice. A provision in a by-law fixing a stated or permanent place for such sales would not be a reasonable one, as the place as well as the time of such sales is not a matter of permanency, but is subject to the fluctuating demands of expediency. Such a sale of stock on due notice as to the time and place can not be held invalid because the by-laws of the corporation did not prescribe the place where such sales should be made.

Mitchell v. Blue Star Min. Co. (Washington), 167 Pacific, 130, p. 131.

RIGHT OF CORPORATION TO PURCHASE ITS STOCK.

A mining corporation can not ordinarily purchase its own stock as this would amount to a reduction of its capital stock in contravention of the statute. But a mining corporation may acquire its own capital stock in settlement or payment of an indebtedness to it. This exception is supposed to rest on a necessity which arises in order to save loss. And an assessment levied upon stock for the purpose of collecting the unpaid stock subscription is an indebtedness for which the corporation can purchase the stock when offered for sale.

Mitchell v. Blue Star Min. Co. (Washington), 167 Pacific, 130, p. 131.

CORPORATION HOLDING STOCK OF ANOTHER—DUTY OF PRESIDENT.

When a mining corporation acquires a majority of the stock of another mining corporation, it assumes the obligation to manage the affairs of the controlled corporation for the benefit of all the stockholders and not for its own advantage. It is the duty of the president of a mining corporation, who was one of its directors, to conduct the company's affairs with an eye single to the interest of the company.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 974.

ASSIGNMENT OF STOCK PROCURED BY FRAUD—RIGHT OF ASSIGNEE TO SUE.

A stockholder and the secretary of a mining corporation, both familiar with the properties belonging to the corporation and having better knowledge than the other stockholders of the values of its properties, represented to their fellow stockholders that there was an undisclosed purchaser for their stock who would pay \$5 and no more per share if placed in escrow in one block in a certain bank to be taken by such purchaser upon making the payment. They also represented that the stock was not worth more than \$5 per share and could not be sold for more than that sum, and that they themselves would join with their fellow stockholders in placing their stock in such escrow to be sold at \$5 per share. Relying upon these representations and upon the superior knowledge of the situation possessed by the two stockholders and having no knowledge to the contrary, the other stockholders did assign their stock and did place the same in escrow for transfer to such undisclosed purchaser at the stated price of \$5 per share. Thereafter the purchaser went to the bank and on payment at the rate of \$5 per share for the stock received the same and paid to the two conspiring stockholders an additional sum of \$3 per share on all the shares of stock sold. Upon learning of the fraud, the original stockholders, so defrauded, assigned and transferred their respective claims, demands, and causes of action against the two conspiring stockholders in trust for collection and the assignee brought suit against the two conspiring stockholders for damages for the fraud. The rule is that a naked right to sue for fraud and deceit is not assignable; but if an interest in property passes by the terms of the assignment it gives to the assignee the right to enforce the remedies of his defrauded assignors. In this case the several causes of action of the defrauded stockholders were assignable, as they were not merely causes of action for fraud or deceit, but involved substantial rights of property.

McCord v. Martin (Cal. App.), 166 Pacific, 1014.

ULTRA VIRES ACTS—ACQUIESCENCE OF STOCKHOLDER.

The expenditures made by a mining company in a mining enterprise located in a different State and owned by another mining company are ultra vires. But a stockholder who assented to the policy of investing the funds of the corporation in outside enterprises and who himself assisted and was active in making such expenditures and in conducting the enterprise itself can take no advantage of such expenditures in a suit by him against the corporation and a managing director to recover for misappropriation of the corporate funds.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 974.

BY-LAWS—AMENDMENT—ADOPTION AND VALIDITY.

An amendment to the by-laws of a mining corporation made at a regular meeting of the stockholders of the company at which a majority of the stock was represented must be held to be regular and valid.

Mitchell v. Blue Star Min. Co. (Washington), 167 Pacific, 130, p. 131.

BY-LAWS—ASSESSMENT ON STOCK SUBSCRIPTIONS.

A by-law of a mining corporation provided that no assessment should be levied while any portion of a previous one remains unpaid, unless the power of the corporation had been exercised for the purpose of collecting any such previous assessments. The purpose of such by-law is to protect stockholders who have fully complied with assessments made against their stock and all such stockholders were not to be burdened with subsequent assessments until all stockholders had contributed pro rata. Such a by-law can not mean or does not mean that one who fails to pay an assessment against his stock thereby exempts himself against any further assessments.

Pennecard v. Giant Ledge Min. Co. (Washington), 166 Pacific, 629.

BY-LAWS—REPEAL.

The by-laws of a mining corporation provided that they might be altered, amended, or revoked by a majority of the trustees at any monthly meeting, provided notice had been given at a previous meeting of any intended change and that such proposed change could not be acted upon for at least one month from the time of giving notice. On June 9 the trustees, at a regular meeting, made certain changes in the by-laws affecting the manner of making assessments on stock subscriptions. The next regular meeting of the trustee was held July 14, at which time the only business transacted was the approval of the transaction of the meeting of June 9.

In order to affect the repeal of the by-law in controversy it is not necessary to show that notice was given of the intended change where the same trustees were present at both meetings, but the change proposed at the meeting of June 9 would not take effect until the regular meeting of July 14 and at that time the repeal would be effective.

Pennecard v. Giant Ledge Min. Co. (Washington), 166 Pacific, 629, p. 630.

DIVIDENDS—DUTY AND POWER TO DECLARE.

Generally the officers of a corporation are the sole judges of the propriety of declaring dividends; but when directors use their powers illegally, wantonly, or oppressively a court of equity at the instance of a minority stockholder will interfere to prevent such conduct. Thus a minority stockholder may compel the declaration of dividends when he clearly shows that the directors are guilty of fraud or by bad faith in accumulating a large surplus and refusing to pay dividends.

Baillie v. Columbia Gold Min. Co. (Oregon), 167 Pacific, 1167, p. 1168.

See *Baillie v. Columbia Gold Min. Co.* (Oregon), 166 Pacific, 965.

POWERS OF CORPORATION—DECLARATION OF DIVIDENDS—CONTROL BY COURT.

The powers vested in a corporation are exercised by the directors and one of these powers is the declaration of dividend. Ordinarily the question of whether dividends shall be declared by a corporation is one of internal management with which the courts will not interfere. Directors must act honestly and with discretion in the performance of their duties and this principle applies to their actions in the matter of dividends. It is only in a clear case that equity may sometimes compel a corporation to declare dividends. But it must be averred and proved that the board of directors of the corporation has abused its discretion in withholding dividends. If there are reasonable grounds for withholding dividends the discretion of the directors will not be interfered with. An individual stockholder may maintain his action against the corporation for fraudulently withholding his share of the money received by it which ought to have been divided among the stockholders. It is only where a court can see that the powers of the directors will be abused to the injury of the complaining stockholder and that the circumstances clearly call for the declaration of a dividend that a court will interfere.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 969.

DIVIDENDS—DISTRIBUTION OF PROPERTY.

Whether a distribution of corporate property is to be regarded as a dividend or not does not depend upon the status of the person that receives a share but on what is done by the distributor. The

money or property in such case is owned by the distributor and as owner he has the power to decide what is to become of it. After the stockholder receives it he may use it as he likes, but it comes into his hands as dividend whether he is an individual or a corporation. Under this doctrine a principal corporation holding stock of subsidiary companies and receiving property or money from such companies receives it as a dividend, and paying a dividend such principal corporation must pay an excise or franchise tax for 2 months of the year 1913 and an income tax for the remaining 10 months.

Lewellyn v. Gulf Oil Corp., 245 Federal, 1, p. 7.

Reversing, *Lewellyn v. Gulf Oil Corp.*, 242 Federal, 709.

RECOVERY OF DIVIDENDS—LIMITATION OF ACTION.

A minority stockholder began an action in September, 1915, to recover from the corporation his share of dividends on the alleged grounds of a wrongful conversion of the corporate funds by the person who elected the directors and controlled the management of the corporation and had fraudulently converted the funds of the corporation to his own use. The complainant alleged that the moneys were misappropriated and converted in the years 1898, 1900, and 1901 without his knowledge, and that the entries in the books of the mining corporation were made long after the alleged misappropriations. The complainant alleged that at the time of the beginning of the suit the defendants, except the mining corporation, resided in another State. No other excuse for the long delay in bringing suit was alleged or given. Under the statute of Oregon an action at law to recover a dividend must be brought within six years and if a suit in equity is brought after the expiration of the time allowed to sue at law the complainant must explain the delay in his bill and sufficiently allege the impediments to an earlier prosecution of his claim. It is true that the statute of limitations does not begin to run against a stockholder claiming a dividend until the dividend is declared; but the principle can not apply where the stockholder contends that the fraud of those in control of the corporation constituted an equitable declaration of a dividend and where it appears that the fraud depended upon was perpetrated more than six years prior to the bringing of the suit.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 971.

MISAPPROPRIATION OF CORPORATE FUNDS—LIABILITY—STATUTE OF LIMITATIONS.

A majority stockholder in a mining corporation, alleged to have converted and wrongfully appropriated to his own use the corporate funds, is liable to account for the same in a proper action, and he can not successfully plead the statute of limitations to such an action

unless he can show that he has been in the State of the residence of the corporation more than six years since the date of the alleged conversion.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 971.

RIGHT OF STOCKHOLDER TO SUE FOR COMPANY.

Whether or not a mining corporation shall seek to enforce in the courts a cause of action for damages is ordinarily a matter of internal management within the discretion of the board of directors in the absence of instructions by a vote of the stockholders. Courts interfere seldom to control such discretion intra vires the corporation, except where the directors are guilty of misconduct equivalent to a breach of trust or where they stand in a dual relation which prevents an unprejudiced exercise of judgment. Where there is no allegation that a mining company is in the control of the alleged wrongdoers or that its directors have been guilty of any misconduct whatsoever, and no allegation that their action in refusing to bring suit is unwise, and where no application was made to the stockholders as a body and no opportunity given to make it, and where the course pursued by the directors may have the approval of all the stockholders except the suing plaintiff, a court will not interfere with the management of the corporation and will not permit a single stockholder under such circumstances to maintain an action at law against the corporation. The fact that the cause of action is based on the alleged violation of the Sherman antitrust law does not give to individual stockholders the right to interfere with the internal management of the corporation.

United Copper Co. v. Amalgamated Copper Co., 244 U. S., 261, p. 263.

RIGHT OF MINORITY STOCKHOLDER TO SUE.

A minority stockholder in a mining corporation can not in the first instance maintain an action against the corporation and the directors and officers for the conversion of the corporate funds, as such wrongs are primarily wrongs done the corporation itself and the injury sustained by the complainant as a stockholder was consequential, and the right of action for the recovery of the moneys alleged to have been taken and converted is primarily in the corporation itself.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 969.

A minority stockholder can not maintain an action in his individual capacity against the corporation and the directors, other corporations, and an individual who controlled all the corporations named where his action does not purport to be brought on behalf of all stockholders similarly situated, and where the complaint fails

to allege a demand on the board of directors to bring suit in the name of the corporation and no sufficient excuse is stated for such failure to make the demand. The failure to make these averments is not excused by an averment to the effect that the plaintiff is the only stockholder not concerned in the frauds complained of. A minority stockholder has a right to sue on behalf of the corporation in a proper case.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 970.

RIGHTS OF MINORITY STOCKHOLDER—REMEDY—RECEIVER.

A majority stockholder in a mining corporation elected the directors and himself controlled and managed the business of the corporation, converted and misappropriated the funds of the corporation and invested and used them in the business and operations of other corporations managed by him, and removed the books and records of the mining corporation from the State of its residence to a distant State and refused inspection thereof by a minority stockholder. This method of conducting the business of the corporation extended over a period of 15 years with no accounting to the mining corporation and no dividends being declared by its directors. A minority stockholder in the mining corporation who mistook his remedy and brought his action directly against the corporation, the directors, and the majority stockholder who so mismanaged and converted the funds of the corporation, though not permitted to recover in such an action, may have his remedy by amending his complaint and asking for the appointment of a receiver to take charge of the property of the mining corporation, to compel the return of the books, and require a proper accounting and the return of all moneys due the corporation.

Baillie v. Columbia Gold Min. Co. (Oregon), 166 Pacific, 965, p. 975.

PURCHASE OF PROPERTY BY STOCKHOLDERS—GOOD FAITH AND VALIDITY.

A mining corporation purchased a mining claim for a stated consideration, payment to be made in installments from a certain portion of the proceeds of the mining, with an option to abandon the tract, the only penalty being a forfeiture of the payments made. The mining enterprise was not a success, and for the want of funds on the part of the corporation operations were shut down. The company made some payments out of money borrowed or contributed by stockholders and was in debt to the stockholders for the sums advanced or paid. Under such circumstances it can not be held that the corporation was injured where certain stockholders who had made considerable advances secretly purchased the mining claim for their own protection and without any intention of making

any secret profit at the expense of the corporation. The purchasing stockholders did not use their position or their knowledge to prevent the company from accomplishing its purpose or acquiring the property in accordance with its plan. They took nothing which belonged to the corporation and imposed upon it no new burden in accomplishing its purpose and did not stand in such fiduciary relation as to raise a constructive trust because of a breach of duty.

Munro v. Smith, 243 Federal, 654, p. 657.

MORTGAGE—FRAUDULENT SALES OF STOCK—KNOWLEDGE OF MORTGAGEE.

A mortgagee is not to be denied the right to foreclose his mortgage executed by a mining corporation on a mining claim on the ground of fraudulent sales of the capital stock of the mining corporation, where there is no evidence to show that the mortgagee had any part in any such fraudulent sales.

Myers v. Indiana Min. Co. (Oregon), 168 Pacific, 719, p. 720.

STATUTE REQUIRING CORPORATIONS TO SELL LAND—APPLICATION.

An oil and gas service corporation comes within the provisions of the statute of Oklahoma (Session Laws, 1907-8, chap. 13), requiring all corporations doing business in the State to sell and dispose, within a period of seven years, of all the real estate owned by it other than that within the corporate limits of cities and towns, unless the same shall be necessary and proper for carrying on the business for which such corporation was licensed or chartered.

State v. Prairie Oil & Gas Co. (Oklahoma), 167 Pacific, 756.

BONDS—PARTITION—ESTOPPEL.

A bank held a mortgage on certain mining properties to secure the debt of two of its directors, who were the owners of the mining property. Subsequently the debtors induced the bank to release them and to accept bonds of a mining corporation to the amount of the debt, secured by a mortgage on the same mining property. The debtors, without the knowledge of the bank, issued bonds on a parity with those issued to the bank and largely in excess of the value of the mining property. Under such circumstances the bonds held by the bank must take precedence and have superiority over the other bonds issued and the property of the mining corporation must first be devoted to the payment of the bonds held by the bank.

Mercantile Trust Co. v. Sunset Road Oil Co. (California), 168 Pacific, 1033, p. 1034.

Mercantile Trust Co. v. Sunset Road Oil Co. (California), 168 Pacific, 1036.

INJUNCTION—PARTIES.

A mining corporation in Mexico held the legal title to certain mining property, but all of its capital stock was turned over to an Arizona corporation which was to finance and operate the mining property. The Arizona corporation sold a part of the capital stock to another mining company and to the president and organizer of the Mexican and Arizona companies and pledged the remaining shares to secure an indebtedness of the president. The pledgee of the part of the stock assumed control and reorganized the Mexican corporation and through a board of directors controlled by him entered into an agreement for the sale of the mining property. The corporation purchasing a part of the shares of stock of the original Mexican corporation can not maintain a bill to enjoin the reorganized Mexican company from selling the mining property without making the original Mexican corporation and the pledgee of the other shares of the capital stock parties to the bill.

Virginia C. Min., etc., Smelting Co. v. Corrigan, 242 Federal, 809, p. 811.

STATUTE OF LIMITATIONS—WAIVER OF DEFENSE.

In an action by a minority stockholder against a mining corporation and others to recover his share of money abstracted from the corporation, the corporation is the adverse party and is entitled at its election to insist on the defenses of laches and the statute of limitations.

Baillie v. Columbia Gold Min. Co. (Oregon), 167 Pacific, 1167.

See *Baillie v. Columbia Gold Min. Co. (Oregon)*, 166 Pacific, 965.

INCOME—ROYALTIES ON MINES.

Royalties paid by the lessees of mines to the lessor by virtue of leases are not to be viewed as the proceeds of property sold, but as rents and therefore fairly within the term "income" under the corporation tax act.

Phister Land Co. v. City of Milwaukee (Wisconsin), 165 Northwestern, 23, p. 24.

APPOINTMENT OF RECEIVER—POWER OF EQUITY.

It is within the general powers of a court of equity to grant a receiver over a corporation, where, through such receiver, the relief of a minority stockholder can be best worked out. This right is to be exercised sparingly and with great caution to the end that the innocent be not made to suffer with or for the guilty. But where there are no innocent stockholders or creditors liable to injury from the appointment and where the rights of a minority stockholder victimized by the frauds of the majority stockholders can be best secured to him through a receiver, the relief will be granted.

Baillie v. Columbia Gold Min. Co. (Oregon), 167 Pacific, 1167, p. 1169.

EXCESSIVE FREIGHT RATE—RECOVERY.

A mining corporation that has been compelled to pay a greater freight rate for intrastate shipments of coal for a short distance than it or others is required to pay for a greater distance, may under the constitution of Missouri (sec. 12, art. XII), recover any such excess of freight so paid.

Missouri Pacific R. Co. v. McGrew Coal Co., 244 U. S., 191, p. 199.

OWNERSHIP OF SOIL ON BANK OF NAVIGABLE STREAM.

A mining corporation owning coal lands along a navigable river has no right or title to the soil along the bank of the stream, and a contractor employed by the coal company to erect a tipple can not justify the destruction of a sunken vessel in the stream on the ground that the mining company with whom he had the contract had riparian rights.

De Bardeleben Coal Co. v. Cox (Alabama), 76 Southern, 409, p. 410.

TIPPLE SITE—CONDEMNATION OF LAND.

The statute of Utah gives a local company the right to condemn land for a tipple site for handling and loading coal on cars.

Ketchum Coal Co. v. Pleasant Valley Coal Co. (Utah), 168 Pacific, 86, p. 93.

COAL COMPANY LIABLE FOR WATER SUPPLY.

A coal-mining company under a contract by which a water company was to furnish it 250,000 gallons of water a day at the rate of 5 cents per thousand gallons is not liable for the full amount of water stipulated, regardless of the amount used, where the water company did not obligate itself to furnish that amount per day and where a minimum rental per year was expressly stated.

Mountain City Water Co. v. Harleigh-Brookwood Coal Co. (Pennsylvania), 101 Atlantic, 734.

INCOME TAX—LAW GOVERNING.

A resident corporation receiving rents in the form of royalties upon leased mines located in a foreign State, is subject to the income tax act of 1911, as the question as to whether royalties paid annually on such mines are rentals is to be determined by the law of this State and not according to the law of the State where the mines are located.

Piester Land Co. v. City of Milwaukee (Wisconsin), 165 Northwestern, 23, p. 25.

FOREIGN CORPORATION—APPEARANCE TO ACTION—JUDGMENT BINDING.

A foreign corporation that voluntarily appears to an action pending in a State other than that of its State, is bound by the judgment entered and it is immaterial whether or not the corporation was

engaged in business in the State where the judgment was rendered or had property there, or had complied with the statute requiring it to designate an agent in the State on whom service might be had.

Blue Goose Min. Co. v. Northern Light Min. Co., 245 Federal, 727, p. 730.

NONRESIDENCE—JOINDER WITH RESIDENT—REMOVAL OF CAUSE.

A nonresident mining corporation joined with a resident in an action for damages for injuries due to the alleged negligence of the mining corporation and of the resident codefendant is not entitled to removal of the cause to the Federal court merely on the ground of alleged fraudulent joinder for the purpose of jurisdiction without proof of fraud or fraudulent purposes in joining the nonresident corporation with the resident defendant.

West Kentucky Coal Co. v. Key (Kentucky), 198 Southwestern, 724, p. 725.

REMOVAL OF CAUSE—FINDING IN FAVOR OF RESIDENT CODEFENDANT.

A mining corporation organized in the State of New Jersey was carrying on its mining operations in Kentucky. A miner injured by the defective electrical appliances of the mining company brought suit for damages against the nonresident mining corporation and the resident electrician, in its employ, alleging that the injuries complained of were due to the negligence of both. Upon the trial of the case on its merits, the jury found in favor of the resident electrician and against the mining company. The verdict in favor of the resident defendant did not operate to make the cause then removable and it can not be regarded as conclusive of a fraudulent joinder for the fraudulent purpose of giving a State court jurisdiction over the nonresident corporation.

West Kentucky Coal co. v. Key (Kentucky), 198 Southwestern, 724, p. 725.

MINING CLAIMS.

NATURE AND GENERAL FEATURES.

NUMBER OF LOCATIONS UNLIMITED.

Congress has not fixed any limit to the number of locations that may be made by the same person or persons, but its policy has always been to encourage the exploration of the public lands and the discovery and development of such minerals as may be found in them.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 523.

SALE OF INTEREST—CASH VALUE.

The price fixed by an agreement to purchase a mining claim, the sum payable in monthly installments out of the net returns of the mining, with the guaranty of certain minimum monthly payments, in order to acquire a full title and with the privilege of abandoning the tract at any time by forfeiting payments made, is a most uncertain indication of the actual cash value of the property. As the payments are optional and made contingent upon success, the vendors may ask more and the vendee may be willing to pay more than in an outright cash purchase.

Munro v. Smith, 243 Federal, 654, p. 657.

MINERAL CHARACTER—JURISDICTION OF LAND DEPARTMENT.

The Land Department has jurisdiction and full authority on its own motion or at the instance of others to inquire into the bona fides of a claimed settlement upon public land, though unsurveyed and though no entry based upon the settlement has been allowed, and to determine as a question of fact the mineral character of the land and the validity of a mining location in a national forest, although the locator has not applied for a patent.

Nicholas & Smith, In re 46 Land Decisions, 20, p. 26.

VEIN OR LODGE.

PRESUMPTION AS TO DIRECTION.

Where a mining claim has been duly located on the apex of a vein and the vein has in part been disclosed, and so far as thus known its course or strike is parallel to the side line, it may be inferred or presumed that the strike of the undisclosed portion is substantially the same as that which has been exposed. But this is an inference

of fact and not a presumption of law. It does not follow from the location of the claim or the directions of the boundary lines thereof, but from the actual course of the apex of the portion of the vein as disclosed.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 469.

PRESUMPTION AS TO CROSSING SIDE OR END LINES.

Where a vein or lode in an established mining claim is found to have a certain course so far as it is disclosed, an inference may be drawn that it will continue in the same direction. If a vein crosses an end line and for some distance the strike is parallel to the side lines, it is not unreasonable to conclude that the vein continues in that direction. But where a vein enters a claim by intersecting a side line instead of an end line, and so far as it is definitely determined its course is more nearly parallel with the end lines than with the side lines, if any inference is to be drawn, it must be to the effect that the vein intersects the other side line rather than the other end line. But where a vein on entering a claim crosses a side line at an angle and its direction is unknown or is irregular, there is no more reason to infer that it passes out of the claim through an end line than through the other side line. No presumption on this subject will be indulged where there is no substantial basis on which an intelligent estimate of the probability can be made.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 469.

MINERAL CHARACTER OF LAND.

DETERMINATION—JURISDICTION OF LAND DEPARTMENT.

In an application for a patent for an alleged mining claim the Land Department possesses the jurisdiction to inquire into and determine the facts as to the mineral character of the land embraced in the location sought to be patented, and it has the jurisdiction to determine the mineral character of a mining location situated within a national forest reserve.

Cameron v. Bass (Arizona), 168 Pacific, 645, p. 646.

MINERAL CHARACTER OF LAND—VALIDITY OF LOCATION.

The determination by the Land Department in an application for a mining location that the land embraced within the location is non-mineral, and therefore not subject to location under the mining laws, renders the location void ab initio, and such pretended location gives the locator no rights therein. The locator's possession of such a claim is subject to termination by the Government at any time and is terminated by being set aside and included within the boundaries of a national forest reserve.

Cameron v. Bass (Arizona), 168 Pacific, 645, p. 647.

LOCATION OF CLAIM.**ORDER OF PERFORMANCE OF REQUIREMENTS.**

Where no rights of third persons intervene the order in which the statutory requirements concerning the making of mining locations are complied with is immaterial. The marking of the boundaries of a claim may precede the discovery, or discovery may precede the marking, and if both are completed before the rights of others intervene, the earlier act will inure to the benefit of the locator as of the date of the later, and a complete possessory title to the location will vest in the locator as of the later date.

Consolidated Mutual Oil Co., v. United States, 245 Federal, 521, p. 524.

LOCATION NOTICE AND CERTIFICATE.**VALIDITY—EFFECT ON TITLE.**

Recorded certificates of location constitute the first muniment of the locator's paper title, and when verified are, by the statute of Montana (Codes, 1907, secs. 2284–2285), made *prima facie* evidence of all facts properly recited therein. When such certificates are apparently valid but under the mining laws are actually invalid, they constitute a cloud upon the locator's title.

Hopkins v. Walker, 244 U. S., 486, p. 491.

DISCOVERY.**ELEMENTS AND WHAT CONSTITUTES.**

Diligent prosecution of work leading to discovery upon a mining claim depends so largely upon the physical conditions of the locality, the nature and situation of the region, its accessibility, the magnitude of the work, the difficulty of securing materials and supplies and the like, that each case must rest largely upon its own facts and circumstances, and a decision in one may be of little assistance in another.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 727.

LOCATOR PROTECTED.

A locator who has properly marked his location in compliance with the provisions of the statute and is in actual possession of his claim and is making bona fide efforts leading to a discovery, will be protected by the courts against any forcible, fraudulent, surreptitious or clandestine entry by any third party.

Consolidated Mutual Oil Co., v. United States, 245 Federal, 521, p. 524.

ASSOCIATION CLAIM—SINGLE DISCOVERY.

Marking boundaries, doing assessment work, and expenditures for patent on an association claim of 160 acres are treated as an entirety under one location, and for the purpose of discovery it shall

be treated in the same manner. A single discovery on such a claim is sufficient to support the location.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 523.

CANCELLATION—RULE OF PROPERTY.

The rule that mineral entries in the Warren mining district would not be canceled, although without any actual discovery of a vein or lode but made upon land which was found to be mineral in character, has become a rule of property recognized and followed by the Land Department. This rule of property can not apply to locations made after the rule of property was announced, and especially where the mining location in controversy was not made upon lands known to be mineral in character, but in fact upon land already entered under the homestead law.

Gonzales v. Stewart, 46 Land Decisions, 85, p. 88.

EXTRALATERAL RIGHTS.

RIGHT TO FOLLOW VEIN—BURDEN OF PROOF.

Where the owner of one mining claim seeks to follow his vein beneath the surface of another claim, he has asserted an extraordinary right not incident to ownership under the common law but conferred by statute. In an action to enforce such a right he assumes the burden of proof, and it is incumbent upon him to show by a preponderance of the evidence that the location of his claim under the law entitles him to follow the vein or lode apexing therein to and into such other claim.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 468.

VEIN CROSSING END LINE.

The owner of a mining claim can not follow the vein or lode apexing in his claim, on the theory of extralateral rights, beyond the vertical plane of a side line unless the vein intersects at least one of the end lines.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 468.

VEIN CROSSING SIDE LINE.

The owner of a mining claim has no extralateral rights on a vein apexing in his claim where such vein crosses the side lines instead of the end lines. Where this is true he is not entitled to pursue the vein on its dip beyond the vertical plane of his side line.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 470.

ASSESSMENT WORK.

GROUP CLAIMS—ASSESSMENT WORK—BENEFICIAL EFFECT.

Where two or more contiguous claims are held by the same person or persons, work done in good faith upon one of them or outside of

the boundaries of either of them that directly tends to the development or benefit of all the claims for mining purposes, is applicable to each and all of such claims and is a compliance with the statute relating to assessment work.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 523.

ASSESSMENT WORK UPON GROUP CLAIMS—NUMBER LIMITED.

Congress by an act approved February 12, 1903 (32 Stat. at Large, 825), provided that where oil lands are located as placer mining claims, the annual assessment labor upon such claims may be done upon any one of a group of claims lying contiguous and owned by the same person or corporation, but the act expressly limits the right to do such work to claims not exceeding five in all. The labor must tend to the development, or to determine the oil-bearing character, of such contiguous claims.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 523.

POSSESSORY RIGHTS.

ASSIGNMENT—RIGHT OF ASSIGNEE.

A person in possession of a mining claim, claiming under an alleged locator either as assignee or as his representative or agent, can have no greater rights than the locator himself.

United States v. Brookshire Oil Co., 242 Federal, 718, p. 721.

RIGHTS AND INTERESTS—OWNERSHIP OF SURFACE.

The owner of a mining claim is *prima facie* the owner of the surface and of all beneath the surface, and this presumption of exclusive ownership is effective to repel intrusion by anyone who does not come clothed with a title acquired by virtue of a compliance with the provisions of the statute.

Bourne v. Federal Min. & Smelting Co., 243 Federal, 466, p. 468.

TRANSFER OF RIGHT OF POSSESSION.

The right possessed by the locator of a mining claim to maintain his possession against intruders while in good faith seeking to discover minerals within the boundaries of his claim is a right of value and it may be transferred or conveyed to another.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 525.

MINING CLAIM AS PROPERTY.

A mining claim perfected under the law is property in the highest sense of the term and may be bought, sold, and conveyed and will pass by descent.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 527.

POSSESSORY ACTIONS.**ACTIONS TO QUIET TITLE—JURISDICTION OF FEDERAL COURTS.**

The owner of a patented placer claim filed a bill in equity to quiet his title against certain lode locators in which he alleged that at the time of his application for patent no mineral vein or lode was known to exist within the boundaries of his placer claim; that pending his application certain lode claimants filed adverse claims seeking to establish their rights to lode locations within the limits of the placer claim; that judgments were rendered in favor of the placer applicant and that upon final hearing a patent to the placer claim was issued. The bill further alleged that notwithstanding such adjudication the defendant subsequently made pretended lode locations within the limits of such placer claim; caused their certificates to be recorded, and that such certificates as recorded constitute clouds upon the complainant's title. Such allegations plainly show that a controversy respecting the construction and effect of the United States mining laws is involved and is sufficiently real and substantial to bring the case within the jurisdiction of a Federal court.

Hopkins v. Walker, 244 U. S., 486, p. 488.

QUIETING TITLE AGAINST INVALID CERTIFICATES.

A locator or the owner of a placer mining claim may maintain a bill in equity to quiet his title against recorded certificates of lode locations made within the limits of his placer claim in violation of his rights and which certificates in fact constitute a cloud upon his title.

Hopkins v. Walker, 244 U. S., 485, p. 491.

ACTION TO ENFORCE RIGHTS.

A person who has made a discovery of minerals within the boundaries of this claim, has performed other necessary acts of maintaining the boundaries on the ground, the posting and recording of the location notice, sinking of the discovery shaft, and who has each year from the time of his location performed the necessary amount of the required annual work and labor, has performed at least \$100 worth of work and improvements upon the claim each year, shows a prima-facie right to the exclusive possession of the claim and may maintain an action to enforce such right and to restrain a trespass upon his claim.

Cameron v. Bass (Arizona), 168 Pacific, 645, p. 646.

PATENTS.**CONSTRUCTION AND VALIDITY—VACATION—COLLATERAL ATTACK.**

A patent to a mining claim or to agricultural lands subsequently claimed to be mineral is an adjudication by the Land Department

and a conveyance of the title to the land which the patent described, and raises a presumption of right and regularity in all the proceedings antedating it and of perfect title in the grantee. When a patent is issued for agricultural lands it is an adjudication of the Land Department that the land so granted was not mineral land, and such adjudication is impervious to collateral attack. The Government may avoid such a patent by suit in equity for false and deceitful representations of material facts which induced its issuance, but the burden is upon the Government in such an action to establish the fraud charge, not only by a preponderance of conflicting evidence but by evidence that commands respect and that amount of it which produces conviction.

United States v. Beaman, 242 Federal, 876, p. 879.

TRESPASS.

VALIDITY OF LOCATION—NONMINERAL LAND—PLEADING.

In an action by the locator of a mining claim to restrain an alleged trespass where he avers sufficient facts to make a *prima facie* case of his right to possession, an answer setting up that the land located was in fact nonmineral and that patent had been denied the complainant by the Land Department because of its nonmineral character, states new matter and must be denied by the complainant or it will be taken as true.

Cameron v. Bass (Arizona), 168 Pacific, 645, p. 646.

PLACER CLAIMS.

ASSOCIATION LOCATION—SINGLE LOCATION.

A location made by an association of persons is one location covering 160 acres and not eight locations covering 20 acres each. It is in law a single location and as such a single discovery is sufficient to support such a location.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521.

NUMBER PERMITTED TO EACH PERSON OR ASSOCIATION.

There is no limit as to the number of mining claims an individual or an association of individuals may locate, but no claim shall exceed 20 acres for each individual or 160 acres for any association. This is a positive limitation of the amount of mining ground that any one claimant may appropriate individually or as a member of an association in any one claim, and he can not evade the law by the use of the names of friends, relatives, or employees. Any device whereby one person is to acquire more than 20 acres or an association more than 160 acres in area by one discovery is a fraud against the Government and is without legal support and void.

United States v. Brookshire Oil Co., 242 Federal, 718, p. 721.

CONVEYANCE INCLUDES KNOWN VEIN.

The conveyance of a placer claim, as a matter of law, includes all known veins and lodes of quartz within its limits.

Wilbur v. Everhardy (California), 167 Pacific 861, p. 862.

QUIETING TITLE AGAINST LODE CLAIMANT—FEDERAL JURISDICTION.

A cause of action arising under the mining laws of the United States where the allegations of a bill to quiet title by the owner of a patented placer mining claim, in a suit against certain pretended lode locators whose pretended locations were made and whose certificates of such locations were filed after the complainant's placer patent was issued, sufficiently disclosed that it really and substantially involved a dispute or controversy respecting the validity, construction, or effect of a law of Congress. It is sufficient if the plaintiff's cause of action, unaided by any anticipation or evidence of defense, disclosed that it really and substantially involved a dispute or controversy respecting the validity, construction, or effect of a Congressional enactment.

Hopkins v. Walker, 244 U. S., 486, p. 489.

**LODE LOCATIONS WITHIN PLACER LIMITS—QUIETING TITLE—
JURISDICTION.**

Section 2333, United States Revised Statutes, authorizes a person to enter upon a patented placer claim and locate within such claim a lode or lodes known to exist at the time of the filing of the application for a placer patent. The owner of a patented placer claim may bring suit to quiet title against a subsequent lode locator and show an adjudication in his favor as to the nonexistence of lodes within his placer limits. The allegations of his bill as to the existence, invalidity, and recording of the defendant's certificates of such pretended and invalid locations form a part of the complainant's cause of action, as the facts showing the plaintiff's title and the existence and invalidity of the instrument or record sought to be eliminated as a cloud upon the title, are all essential parts of the complainant's cause of action.

Hopkins v. Walker, 244 U. S., 486, p. 489.

OIL LOCATION.**GOOD FAITH OF LOCATOR.**

Oil locations under the placer mining laws can not be sustained as valid locations where one person used names of others in an attempt to secure for himself an area of mineral land in excess of that allowed by law. The fact that the notices and all matters in

connection with the locations were prepared, initiated, and attended to by the person interested without previous authority from the persons whose names were used; that immediately after posting the notices the interested person began dealing with the property as his own without the knowledge of the locators named and without obtaining authority from them and without advising them of his intention or purpose; that after entering into a contract with an operating company for the development of the claims, he requested the execution of powers of attorney prepared by him and they were accordingly executed; that subsequently the several parties executed deeds to such interested person for nominal considerations, fixed by the interested person himself, clearly show that the person interested did not act in good faith for the benefit of the alleged locators, but was attempting to acquire the ground for himself.

United States v. Brookshire Oil Co., 242 Federal, 718, p. 720.

PARTY IN POSSESSION—CLAIM TO PROTECTION.

A person or corporation in possession of an oil claim as the representative, agent, or contractee of the original locator can not claim protection under the act of June 25, 1910, known as the Pickett Act (36 Stat., 847), as against a withdrawal order, where the locations were not made in good faith by the original locator and were in fact invalid.

United States v. Brookshire Oil Co., 242 Federal, 718, p. 722.

See United States v. North American Oil, Consolidated, 242 Federal, 723.

DISCOVERY—SEEPAGE.

While it is possible that at times oil may be found issuing from the surface of the ground, known in practice as seepage, in which case discovery may be made without difficulty or expense, it is a matter of common knowledge that almost always drilling is essential to such discovery, and in many sections drilling to great depth, involving heavy cost.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 525.

DISCOVERY—DILIGENT PROSECUTION OF WORK—WITHDRAWAL ORDER.

The original locator of oil lands on the public domain by a lease dated June 25, 1909, leased the locations, including in all two 80-acre tracts and two 160-acre tracts of a certain section of land. The lessee immediately entered into the exclusive possession of all the lands included in the lease. The lease upon a royalty basis provided for the drilling of wells upon each of the quarter sections embraced by the lease, in the effort to discover and take oil therefrom, for

continuous and diligent work by the lessee to that end, and for the working of all the claims as a unit. Between the date of the lease and September 27, 1909, the lessee built a 2-inch pipe line more than 3 miles in length to connect with the main of a water supply company, constructed a standard derrick on each of the claims, built on one quarter of the section a water tank with pipe-line connections, a bunk house and a cookhouse containing a dining room sufficient for the seating of 40 men, a kitchen, and bedroom. On another quarter section the lessee built another bunk house 20 by 30 feet in size; and on another section the lessee built a stabling yard for freight teams and for a buggy and horses, building also a boiler house and erecting machinery for operating one full string of tools for drilling at the derrick on one quarter section. On the 27th day of September, 1909, the lessee was in the undisputed possession of all the property and was actually drilling a well by means of a derrick on one quarter that had reached the depth of 830 feet. The lessee had abundant means to carry out his undertaking, and but for the impossibility of securing the necessary water would have been sinking a well at each of the derricks on the other quarters of the section. The lessee intended and in fact had directed the successive sinking of the other wells as soon as oil should be struck in the first one and was so intent on the speeding of the work as to offer to pay a bonus to the employees for extra work. Up to the 27th day of September there had been no discovery of oil or any other mineral on any of the land and on that date the President by proclamation and a withdrawal order withdrew from location many tracts of land, including those covered by the lease. At the time of the withdrawal order the lessee had in the lands in question valuable rights of possession and conveyance which the courts would protect and enforce and consequently valid rights that he had acquired by the license, if not by the invitation of the Government, and in pursuance of which the lessee had expended more than \$20,000 and which he continued diligently to explore and develop at very large additional expense for years thereafter without objection on the part of the Government. Subsequently an assignee of the lessee was permitted, upon due application to the Land Office, to enter the lands described in the lease and for which he paid the Government \$1,600, receiving therefor its register's final certificate of entry dated October 31, 1914, and which certificate remains uncanceled. Under the facts and circumstances the lessee was in diligent prosecution of work leading to a discovery within the meaning of the act of June 25, 1910 (36 Stat., 847), and his rights were not affected and his title not forfeited by the President's withdrawal order.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 525.

PERSONS PROSECUTING WORK OF DISCOVERY—PROTECTION.

The act of June 25, 1910 (36 Stats., 847), known as the Pickett Act, was intended and designed for the benefit of those who were intending at the date of the withdrawal to acquire title or right of possession to mining ground by complying in good faith with the mining laws of the United States. The act can not be extended to protect a person, his representative or agent, who is seeking to evade the mining laws and obtain title in violation thereof.

United States v. Brookshire Oil Co., 242 Federal, 718, p. 722.

See United States v. North American Oil, Consolidated, 242 Federal, 723.

PROTECTION AGAINST WITHDRAWAL ORDER.

To bring an occupant or claimant of an oil claim within the provisions of the Pickett Act, the law does not require any unusual or extraordinary effort, but only that which is usual, ordinary, and reasonable under the circumstances. The law does not require a vain or useless thing to be done and an oil company in possession of an oil location at the time of a withdrawal order was not required by the law of diligence to have installed all of its machinery, or commence drilling before a supply of water was such that it could reasonably hope to successfully continue the work, nor is it required to make any unusual or extraordinary effort to obtain water, but only such as was reasonable under the circumstances confronting it. It is sufficient if the company is in diligent prosecution of work leading to discovery at the date of a withdrawal order.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 727.

LOCATOR PROTECTED AGAINST WITHDRAWAL ORDER.

To bring an occupant or claimant of oil or gas bearing lands within the provisions of the act of June 25, 1910 (36 Stats., 847), known as the Pickett Act, it is not necessary that such locator was engaged in actual drilling for oil or gas on a particular tract of land at the date of a withdrawal order, or necessarily that work was then being performed upon the identical claim upon which discovery ultimately must be made in order to make location. It is sufficient if reasonable effort was being made at that time indicating a bona fide intention to complete the work of discovery on the particular claim with all practical expedition. This intention may be manifested by the doing of physical acts which have a direct tendency to facilitate the exploration for a discovery of oil or gas thereon, although actual drilling had not commenced and the work done may not have been on such claim.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 727.

OCCUPANT PROTECTED AGAINST WITHDRAWAL ORDER.

The act of Congress of June 25, 1910 (36 Stat., 847), provided that the rights of a bona fide occupant or claimant of oil-bearing lands who at the date of a withdrawal order was in diligent prosecution of work leading to a discovery of oil should not be affected by such order, was the first legislative recognition ever made by Congress of any right on the part of an occupant or claimant of oil-bearing lands prior to a discovery of oil thereon. By this act, which is remedial and is to be liberally construed, Congress expressly gave to a good faith occupant or claimant of oil or gas bearing lands, who at the date of the act was in diligent prosecution of work leading to discovery of oil or gas, a status. The locator of an oil claim, his assignee or lessee who at the time of the passage of the act was in the actual and exclusive possession of certain oil locations and was in diligent prosecution of work on one of a group of contiguous claims for the benefit of all, not exceeding five, in an effort to discover oil thereon, and which continuous work resulted in the discovery of oil in each of the quarter sections, and who continued from the date of the passage of the act in diligent prosecution of the work that did lead to such discovery, is within the express provisions of the act.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 527.

EFFECT OF WITHDRAWAL ORDER.

The President's proclamation and withdrawal order of September 27, 1909, provided that all mining locations or claims existing or valid on that date might proceed to entry in the usual manner after field investigation and examination. This proviso was intended to apply to lands upon which discovery was already made and to which locators had already acquired an equitable title, and it was also intended to apply to all locations and claims existing at the time of the making of the withdrawal order to which the locators or claimants had some valid rights. Under this proviso a locator, his assignee or lessee, who had made a valid location and was in the actual work of drilling an oil well and had reached a depth of 830 feet had valuable rights of possession and conveyance which the courts would protect and enforce, rights acquired by the license, if not by the invitation of the Government, and who pursuant thereto had expended more than \$20,000 upon the land, and who thereafter continued diligently to explore and develop and discover and produce oil, was clearly within the proviso of the withdrawal order.

Consolidated Mutual Oil Co. v. United States, 245 Federal, 521, p. 527.

PROTECTION AGAINST WITHDRAWALS—CONTINUOUS PROSECUTION OF WORK.

The act of June 25, 1910, known as the Pickett Act (36 Stats., 847), provides that the right of a bona fide occupant or claimant at the date of a withdrawal order, who was at such time in diligent prosecution of work leading to discovery, shall not be impaired or affected so long as such occupant or claimant shall continue in diligent prosecution of the work—that is, work leading to discovery; but this does not imply that when discovery is made, his right shall no longer continue. On the contrary it means that he may continue the prosecution of the work until a discovery is made and this completes his right to the location under the placer mining laws.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 728.

United States v. Thirty-two Oil Co., 242 Federal, 730.

WITHDRAWAL ORDER—CLAIMANTS PROTECTED.

The act of Congress of June 25, 1910 (36 Stats., 847), known as the Pickett Act, is a congressional modification of a withdrawal order by relieving therefrom all lands included therein occupied or claimed by bona fide occupants or claimants at the date of such order who were then in diligent prosecution of work leading to discovery, so far as the rights of such occupant or claimant were concerned, and as to them the matter stood as if the land had never been withdrawn but remained subject to the disposition of the Land Department.

United States v. Record Oil Co., 242 Federal, 746, p. 749.

United States v. Consolidated Mutual Oil Co., 242 Federal, 746, p. 749.

United States v. Caribou Oil Mining Co., 242 Federal, 746, p. 749.

DILIGENT PROSECUTION OF WORK BEFORE DISCOVERY—WITHDRAWAL ORDER.

Oil locations are authorized to be made under the placer mining laws. Under the United States statutes providing for the location of placer claims such a claim is not perfected and the claimant's right absolute until a discovery of minerals is made. The rule necessarily applies to oil locations. But some considerable time and a comparatively large expense were necessarily involved in making a discovery of oil on the location. Great injustice was done to locators who had made large investments in discovery work where the lands were withdrawn after such investment had been made but before a discovery was effected. To prevent this injustice, Congress passed an act on June 25, 1910 (36 Stats., 847), known as the Pickett Act. This act provided in effect that locators in the diligent prosecution of work looking to a discovery should not be deprived of their rights by a withdrawal order if the work was so diligently prosecuted until a

discovery was made. The statute contemplates that the diligent prosecution of the work shall continue after any such withdrawal order and that it must be continuous until a discovery is made. But where an oil claimant was in diligent prosecution leading to a discovery at the time of a withdrawal order and continued the same after the withdrawal order and finally made a discovery after an investment of a very large sum, the Government can not then forfeit his right and deprive him of his title to the location because he was not as diligent in the prosecution of the work after the withdrawal order as he might have been and as the officers of the Government thought he should have been.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 728.

DILIGENT PROSECUTION OF WORK—WHAT CONSTITUTES.

An oil claimant is in the diligent prosecution of work leading to a discovery within the meaning of the Pickett Act where prior to the date of a withdrawal order the location had been properly made under the United States mining laws and the oil company, with the intention of exploring the property for a discovery of oil, took possession of the claim and purchased the necessary material and caused to be constructed a derrick and a building or buildings for the housing and accommodation of its employees and such as were common in the oil fields and necessary for such purposes. Two boilers had been purchased and transported to the property ready to be set. Thereafter, up to and at the time of the withdrawal order, employees of the oil company were on each quarter section as keepers, digging cellars, clearing up sagebrush, and doing other preparatory work. Tools had not been hung in the derricks or the boilers set because the oil company had been unable to obtain assurances of an adequate supply of water for boiler and drilling purposes. Large quantities of water are required to drill an oil well and a dependable supply is necessary, not only for use in the boilers but in the well itself for drilling. The oil company was compelled to wait until a water supply company enlarged its plant by sinking new wells, laying additional mains, and installing new machinery and held out the reasonable hope and promise that it would soon be able to furnish an adequate supply of water. The oil company did not commence drilling, but intended to do so and did do so as soon as water could be secured, and in the mean time remained in possession of each quarter section with keepers or watchmen in charge, the employees doing more or less work. Subsequently and after a supply of water was obtained drilling was begun, a discovery made, and numerous wells drilled and oil in commercial quantities discovered on each quarter section.

United States v. North American Oil, Consolidated, 242 Federal, 723, p. 725.

United States v. Thirty-two Oil Co., 242 Federal, 730, p. 732.

WITHDRAWAL ORDER—DILIGENT PROSECUTION OF WORK—QUESTION OF FACT.

Whether an occupant or claimant of oil or gas bearing land at the date of a withdrawal order was at that time engaged in diligent prosecution of work leading to discovery is a question of fact and no hard or fast rule applicable to all cases can be laid down by which it can be determined. Each case must depend to a large extent upon its own facts and circumstances.

United States v. Thirty-two Oil Co., 242 Federal, 730, p. 735.

DILIGENT PROSECUTION OF WORK—NATURE OF WORK.

In order to constitute diligent prosecution of work to bring an oil locator or claimant within the provisions of the Pickett Act, it is not necessary that the work being performed at the time of a withdrawal order was on the particular tract in controversy; but before it can be deemed work leading to discovery thereon, it must be presently and purposely designed for that purpose. The drilling of a well on one location would not, however long continued, lead to discovery of oil on another location. It might afford evidence of the probable existence of oil on the other location and justify the expenditure of money in exploring it and, by disclosing the formation, materially aid in subsequent drilling and lessen the expenses. But this result would follow whether the well was drilled by the occupant or claimant of the particular tract or by a third person, and such work on one location or claim can not be held to be work leading to discovery on another. The proviso in the Pickett Act was intended to confer upon persons occupying or claiming in good faith at the time of a withdrawal order of public land within the withdrawn area, and with the bona fide intention of complying with the mining laws and who were at such time in diligent prosecution of work leading to discovery thereon, the right to continue such work if discovery was subsequently made and the right to retain possession and extract the oil, or take title by patent, the same as if the land had not been withdrawn.

United States v. Thirty-two Oil Co., 242 Federal, 730, p. 735.

WITHDRAWAL ORDER—DILIGENT PROSECUTION OF WORK—NATURE AND PLACE OF WORK.

The diligent prosecution of work may be in progress within the meaning of the Pickett Act at the date of a withdrawal order on one of a group of locations, or even extraterritorially to any of them which could properly be held to be work leading to discovery on all such claims, as the building of roads, laying of water mains, estab-

lishing camps, or assembling material and equipment. if such work directly tended to and was purposely designed for the development of each location with all practical expedition.

United States v. Thirty-two Oil Co., 242 Federal, 730, p. 736.

United States v. Stockton Midway Oil Co., 240 Federal, 1006, p. 1012.

ASSESSMENT WORK ON GROUP CLAIMS.

The rule as to group improvement or development or assessment work as authorized by the United States mining statutes has no application to oil locations and to the diligent prosecution of work on an oil claim at the time of a withdrawal order. The Pickett Act was designed for the relief of bona fide occupants or claimants at the date of a withdrawal order who had not but were then intending in good faith to make a discovery and were manifesting such intention by the diligent prosecution of work tending thereto. But the provisions of this act can not be claimed by or extended to a person holding under paper locations, or locations made for the purpose of enabling one party to acquire a larger area of mineral land by one discovery than the law permits him to take or by one who had by means of skeleton derricks, cabins, or by so-called assessment work, was endeavoring to hold oil lands temporarily for speculation or until exploratory work on adjoining land owned or occupied by him or in the vicinity had indicated the oil or nonoil bearing quality of the land.

United States v. Thirty-two Oil Co., 242 Federal, 730, p. 736.

APPLICATION FOR PATENT—FINAL CERTIFICATE.

A final certificate issued by the General Land Office on an application for a patent to an oil claim vests the entryman with an equitable title to the land and a prima facie right to a patent, but this title is subject to the jurisdiction of the Land Department and for proper cause, may be canceled. It may also be canceled and set aside for fraud by a court in a proper suit brought by the Government for that purpose; but until the entry is lawfully canceled the entryman is in possession under an equitable title and the questions held and determined by the Land Department can not be again litigated in a suit by the United States to enjoin the claimant from mining and removing oil from his location and to require an accounting for oil taken.

United States v. Record Oil Co., 242 Federal, 746, p. 748.

United States v. Consolidated Mutual Oil Co., 242 Federal, 746, p. 748.

United States v. Caribou Oil Mining Co., 242 Federal, 746, p. 748.

TRESPASS AND WASTE—INJUNCTION—PARTIES.

In an action by the United States to enjoin and restrain parties in possession of certain invalid oil locations from trespassing thereon and from producing and extracting oil therefrom, marketing companies that purchased the oil from the trespasser and removed it from the premises through their own pipe lines, are not proper parties, where the basis for a court of equity's jurisdiction was the prevention of waste, and where such purchasing companies made no claim of title to or interest in the land.

United States *v.* Brookshire Oil Co., 242 Federal, 718, p. 722.

See United States *v.* Midway Northern Oil Co., 232 Federal, 619.

MINING PARTNERSHIPS.

AGREEMENT CONSTITUTING PARTNERSHIPS.

An agreement between two or more persons to get together and consolidate into one body or into several bodies small holdings of coal in place so as to make them marketable and to dispose of the same and to share the burden and advantages equally is more than a joint adventure. Such an agreement does not contemplate a single transaction but numerous transactions necessarily extending over a considerable period of time. Though it involves a joint interest and a joint adventure, it is a working contract in which capital, enterprise, and labor are combined for the achievement of profitable results. In such an agreement all of the essential legal elements of a partnership are found, and it does not matter that in the execution of the agreement subsidiary or auxiliary agreements must be made for inclusion and exclusion of subjects, as these are incidents of all partnerships that are formed for the purpose of trade or prosecution of industrial enterprises, and this feature of an agreement to buy and sell coal lands does not deprive it of the elements of a partnership contract.

Teter v. Moore (West Virginia), 93 Southeastern, 342, p. 348.

RIGHT OF PARTNER TO SUE AT LAW.

The complainant and defendant entered into an agreement to mine ore under a certain lease entered into with a mining company in the name of the complainant himself. By the agreement the complainant agreed to pay two-thirds of the expense incurred in mining the ore and the defendant agreed to pay one-third thereof, and the net proceeds derived from the ore mined were to be divided between the partners in that proportion. By the terms of the lease the mining company was to ship to market all the ore as mined and retain title thereto until the royalties under the lease were paid. Pursuant to the agreement, ore was mined and sold and on settlement the mining company paid the defendant the balance due the partners under the lease. On refusing to account, the plaintiff sued the defendant for two-thirds of the amount so received by him from the mining company. Ordinarily one partner can not sue another at law to recover an alleged share of the proceeds of the partnership business. But where a partnership is limited to a single venture and where there are no firm liabilities outstanding and there is nothing requiring an accounting in equity,

an action at law may be maintained by one partner to recover his share of the proceeds of the partnership business. If there is any reason why the suing partner should not prevail in such an action, it is the duty of the defendant to plead it as a defense to the action.

Miller v. Gray (Utah), 167 Pacific, 358.

RECOVERY BY ONE PARTNER—VIOLATION OF MORAL OBLIGATIONS AS A DEFENSE.

In an action by one partner against another to recover a balance due from a mining venture carried on under a lease from a mining corporation, the defendant partner, who had received the proceeds of a sale of ore, refused to account and retained the proceeds of the ore, can not defend the action on the ground that the complainant was an employee of the mining company and that in accepting the lease from the company and in carrying on the mining operations he violated a rule of the company by which its employees should not be interested in any leases covering any of the company's workings and thereby violated a moral obligation existing between an employee and his employer. There is no principle of law or rule of morals by which a defendant under such circumstances is entitled to appropriate his partner's money because the partner might have violated some rule of his employer, the mining company. That fact does not give the defendant any right to claim the money paid to him by the mining company itself with a knowledge of all the facts. The rule against public policy has never been so applied as to take property or money from one person to give it to another merely because one of them may not in all things have lived up to the moral code. Courts enforce legal rights as contradistinguished from moral obligations, and where the two unite in the same person both are enforced; but where the legal right is in one against whom the moral obligation is asserted, legal right prevails.

Miller v. Gray (Utah), 167 Pacific, 358.

OPTION CONTRACTS FOR COAL.

A written contract providing for procurement of options on coal in place by one of the parties thereto for the mutual and equal benefit of both and for equality of burden as to expenses and advantages as to profits, under which large areas of coal are purchased and disposed of for profit, constitutes a partnership agreement.

Teter v. Moore (West Virginia), 93 Southeastern, 342, p. 348.

EXTENT OF OPERATIONS.

A partnership agreement specified certain territories for procurement of options on coal in place and specified certain territories in which the enterprise was to be conducted, but with an indefinite

maximum of coal to be optioned. The actual operations conducted by the parties went far beyond the territories expressly mentioned in the agreement, and the coal purchased outside of such territories was naturally in the same way as that contemplated by the agreement. It was consolidated in the same manner by the same character of hazard, labor, and expense, sold to the same party at about the same time and the proceeds included in a statement of resources and liabilities with a summary of the total amount of business done. The same office, office furniture, and clerical help were used, and the records of these outside transactions were kept in the same set of books. These outside and additional transactions must be treated as a part of the partnership affairs and an addition to the written agreement may be inferred by the bringing in of the new subjects and treatment or disposition thereof on the basis of the written agreement.

Teter v. Moore (West Virginia), 93 Southeastern, 342, p. 349.

SETTLEMENTS OF ACCOUNTS—STATUTE OF LIMITATIONS.

A partnership was engaged extensively in the procurement of options on coal in place and in the sale of such option agreements as well as in the sale of the coal itself. The statute of limitations does not run against the unsettled parts of the accounts of partnership accounts. A continuing partnership contract is not subject to the operation of the statute of limitations until it has been completed. But as to matters included in a partnership settlement and as to any settlement made by the partners, the statute of limitations runs from the date of such settlement and bars any item or matter included therein after five years, whether affected or induced by either fraud or mistake. To reach such a matter either at law or equity there must be an allegation and proof of facts sufficient in law to bring it within the exception provided by the statute of West Virginia (Code, sec. 4431).

Teter v. Moore (West Virginia), 93 Southeastern, 342, p. 349.

PARTNERSHIP SETTLEMENT—FRAUD AND CONCEALMENT—STATUTE OF LIMITATIONS—PLEADING.

A bill by the administrator of a deceased partner of a partnership engaged in the purchase and sale of coal in place alleged that the defendant, the surviving partner, was the custodian of the books of the firm; that he had the custody of the social property and funds with authority to incur and make expenses; that he made and caused to be made entries in the books of large sums of money as having been paid out for expenses which were never actually paid and for payment of which there was no obligation on the part of the firm; that the deceased partner, relying upon the honesty and integ-

city of his partner, made no investigation of the books for verification of the settlement and did not suspect the existence of the alleged frauds; and that the defendant procured a settlement with the deceased partner and left in his hands the sums of money so wrongfully charged as secret, wrongful, and clandestine profits. It was not necessary for the bill to charge that the defendant fraudulently concealed the cause of action in order to prevent it from being barred by the statute of limitations, as fraudulent entries of the kind alleged made by a partner having authority to keep the books and pay expenses and charge the same naturally conceal themselves, and allegation and proof thereof make out a cause within the statutory exception. It was the partner's duty when clothed with such power and as a trustee to make full and truthful disclosure of every fact in his knowledge necessary to a full, fair, and honest settlement.

Teter v. Moore (West Virginia), 93 Southeastern, 342, p. 350.

STATUTES RELATING TO MINING OPERATIONS.

CONSTRUCTION, VALIDITY, AND EFFECT.

CONSTITUTIONALITY NOT DETERMINED.

A court will not consider and determine the constitutionality of a statute at the suit of a stockholder of a mining corporation, in which he claims the statute is unconstitutional, where at the same time the stockholder is asserting some right and claiming protection by virtue of the same statute.

Wall v. Parrot Silver & Copper Co., 244 U. S., 407, p. 409.

Woodruff v. Producers' Oil Co., 142 Louisiana, 76 Southern, 803, p. 804.

FELLOW SERVANTS—PERSONS NOT IN SAME GRADE OF SERVICE.

Section 1343 of the statute of Utah (Comp. Laws, 1907) provides that all persons engaged in the service of a common employer and who are in the same grade of service and working together at the same time and place and to a common purpose are fellow servants. Under this section of the statute two miners working on different levels in a mine, although they work to a "common purpose," do not necessarily work "together at the same time and place" and are not fellow servants within the meaning of this section of the statute.

Shields v. Silver King Coalition Mines Co. (Utah), 166 Pacific, 988.

DUTIES IMPOSED ON OPERATOR.

DUTY TO EMPLOY MINE FOREMAN—DUTY OF FOREMAN TO DEVOTE FULL TIME.

The laws of Oklahoma (Rev. Laws, 1910, sec. 3983) require every coal-mine operator to employ a competent and practical inside overseer, called mine foreman, who shall have charge of the inside operations of the mine and shall see that the provisions of the law are strictly enforced. The statute also requires the mine foreman to devote the whole of his time to his duties in the mine when in operation. The statute merely prescribes the minimum duty cast upon the foreman and in no wise limits or modifies the plain meaning of the positive language used in other parts of the statute. The requirement that he shall devote the whole of his time to his duties in the mine means his statutory duties, which require him always to keep a careful watch over the timbering and as far as possible see that as the miners advance their excavations all slate and rock overhead shall be taken down or secured against falling, and constantly to see that every working place is properly secured by props

or timbers, and that no persons shall be permitted to work in an unsafe place except for the purpose of making it safe. The mandatory character of these statutory directions is emphasized by other provisions of the statute. By express provision of the statute and by all the duties imposed upon the mine foreman he is required to devote his whole time to his duties in a mine when in operation.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1025.

VENTILATION—MINE FREE FROM GAS—STANDARD OF DUTY.

For the better protection of the health and lives of men engaged in the dangerous work of mining coal, the legislature, by statute both remedial and penal, have seen proper to prescribe such regulations and conditions under which a mine may be lawfully operated, and one of these conditions is that "all working places shall be kept clear of standing gas." The standard of duty thus defined and imposed upon the operator of a mine in all circumstances is made the criterion of his care for the safety of his employees; his obligation to meet all the statutory requirements is imperative; and neglect so to do, if resulting in an injury to a miner, will in the absence of contributory negligence, render the operator pecuniarily liable.

McAlester-Edwards Coal Co. v. Hoffar (Oklahoma), 166 Pacific, 740, p. 741.

DUTY AS TO LIGHTS ON COAL CARS.

The Virginia statute (Mining Act, 1916) requires the mine foreman to carry a conspicuous light on the front and a light or flag on the rear of every trip or train of cars when in motion; but the provision does not apply to trips being hauled by gathering trams or by mules when coal is being gathered on other than main headings. It was a clear violation of this law and such as to render a mine operator liable where a trip of empty cars was pushed through an entry in a mine and at the same time a trip of loaded cars was pushed through the entry in an opposite direction and the trip of loaded cars had no light attached to the front end of the front car and where miners were required to pass through the entry to and from their work. A miner injured by being struck by the trip of loaded cars without warning and in a place in the entry where it was too dark to see is entitled to recover damages for the injuries so received.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

INSPECTION OF GASEOUS MINE—QUESTION OF FACT.

The statute of Utah (Laws, 1913, p. 122) requires that a mine foreman or fire boss in all mines known to generate explosive gases shall make a careful examination every morning of all places which might endanger the safety of the miners within three hours prior to

the time they shall enter the mine. Whether or not a particular mine was one which was known to generate explosive gases is a question of fact. But where there was no dispute respecting the fact, and where the evidence on the subject that a certain mine generated gas is not contradicted, it is not error for a court to declare the fact to be in accordance with the undisputed evidence. Where a finding with respect to any essential fact must necessarily be in the affirmative, it is ordinarily the duty of the court to declare the fact, and not permit the jury to assume that they may find the fact contrary to the undisputed evidence.

Eleganti v. Standard Coal Co. (Utah), 168 Pacific, 266.

MINES KNOWN TO GENERATE GAS—MEANING.

The wording of the statute is that "in all mines known to generate explosive gases" examination and inspection shall be made as required by the statute. The statute was intended to and does apply to all mines where explosive gases are known to exist, regardless of the quantity thereof. The legislature by the statute withdrew the question respecting the quantity of gas, or whether the quantity was sufficient or otherwise from the judgment of all persons, whether experts or nonexperts, and imposed upon the owner or operator the duty of examination and inspection in all mines where explosive gases in any quantity are known to exist. It is not a question of whether there is explosive gas in the mine in sufficient quantities to make the mine unsafe or dangerous, but the only question that can be considered is: Has explosive gas been discovered in the mine? If it has, the mine is necessarily one which is known to generate explosive gases. If explosive gases are found in a mine, then it is known to exist, and there is no alternative save to follow the requirement of the statute as to examination and inspection.

Eleganti v. Standard Coal Co. (Utah), 168 Pacific, 266.

CONTINUOUS INSPECTION REQUIRED.

Explosive gases were discovered in a mine and were dissipated in the usual way, and the statutory examination and inspection were kept up for some weeks and later discontinued for the reason that no more gases were discovered. Some sixty days after the first gas was discovered and some weeks after the examination and inspection had been suspended a miner was killed by an explosion of gas in the mine. Had the examination and inspection continued it was reasonably certain that the gas which caused the explosion resulting in the death of the miner would have been discovered and the explosion prevented. The duty of a continued examination and inspection is imposed by the statute for the express purpose of obviating the

every condition that arose in the instant case. It is sufficient to bring a mine within the statute if explosive gases were discovered on one occasion, and then the statutory examination and inspection must be continuous thereafter to avoid liability on the part of the operator.

Eleganti v. Standard Coal Co. (Utah), 168 Pacific, 266.

VIOLATION OF DUTY TO INSPECT.

The statutes of Oklahoma as to the duties of a mine foreman, when considered together, impose upon the mine foreman the duty of inspecting working places and entries before entering such places for the purpose of measuring the gobwork; and his failure to do so constitutes a violation of the statute.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1025.

PROPS—APPLICATION OF STATUTE.

The duty to remove loose, overhanging coal, slate, or rock where it is impossible or impractical to prop the roof is required of the operator by statute in travel and air ways, but this provision of the statute can not be extended by construction to include a miner's working place.

Peacock Coal Min. Co. v. Crawford (Indiana Appeals), 117 Northeastern, 504, p. 505.

LIABILITY FOR FAILURE TO FURNISH PROPS—PLEADING.

The duty imposed upon a miner by the Kentucky statute (Stats., 1909, sec. 2739b, subsec. 7) of selecting and marking props desired by him is dependent upon the operator having provided them in a proper place either within the mine or conveniently near thereto. In an action for the death of a miner, caused by the alleged failure of the operator to provide props in a proper place, the complainant is not required to allege a selection and marking by the deceased miner, unless it was made to appear that the props were provided by the mine operator. Allegations in the petition that the mine operator negligently failed to furnish props, and violated his statutory duty in reference to furnishing props, are sufficient to cover every necessary step in furnishing the props and necessarily included the prior duty of providing them. A failure to furnish props must necessarily result from the failure to provide them.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 Southwestern, 633, p. 634.

FAILURE TO FURNISH PROPS—REQUEST BY MINER.

The statute of Kentucky (sec. 2739b, subsec. 7, Stats., 1909), imposes upon the mine operator the duty of furnishing props to a miner; but the miner is first required to select and mark the props

he desires from a supply to be maintained by the mine operator in the mine or within a reasonable distance therefrom. If the mine operator does not supply the props at a place in the mine or within a reasonable distance therefrom, so that they can be conveniently reached by the miners, then a miner is not required to select and mark the props desired; but under such circumstances a request or demand by the miner will be sufficient to impose upon the operator the duty of furnishing the props. The statute requiring the miner to select and mark the props does not apply and is not controlling where the operator himself has failed to place a supply of props within the mine or within a reasonable distance therefrom.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 *Southwestern*, 633, p. 634.

VIOLATION BY OPERATOR.

NEGLIGENCE PER SE.

Where a legislature of a State, having in view the promotion of the safety of the public or of individual members of the public, commands or forbids the doing of a particular act, the failure to do the act commanded or the doing of the act prohibited is negligence as a matter of law, otherwise called negligence per se. This rule obtains, irrespective of the question of the exercise of prudence, diligence, care, or skill and if it is the proximate cause of hurt or damages to another and if such other person is without contributory fault, the case must be decided in his favor and all that remains to be done is to assess his damages.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 *Pacific*, 1024, p. 1027.

Generally the violation of a public duty enjoined by law for the protection of persons or property constitutes negligence per se.

McAlester-Edwards Coal Co. v. Hoffar (Oklahoma), 166 *Pacific*, 740, p. 741.

NOT PROXIMATE CAUSE OF DEATH OF MINER.

The statute of Illinois (Hurd's Revised Statutes, chap. 93), requires a mine operator in case of any accident to the ventilation immediately to have all the workmen come out of the mine and not to send anyone in until the ventilation is restored. The fact that a mine operator violated the statute by sending, after an explosion, a man into the mine to search for an assistant mine manager who had himself gone into the mine after the explosion, can not render the mine operator liable for the death of the miner so sent into the mine, where the operator subsequently by telephone called the miner and on his answering informed him that the assistant mine manager had come out of the mine and thereupon directed and positively ordered him to come back out of the mine, and where in violation of such order and with knowledge of the dangerous condi-

tion of the mine, the miner proceeded into the dangerous part of the mine and lost his life by being overcome by gas.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 773, p. 776.

RIGHT OF ACTION.

Any person of a particular class for whose special benefit a penal statute is enacted has a right of action for injuries resulting to him from its violation. Under this rule the Virginia statute requiring mine operators to carry a light on the front or rear of coal cars, gives a miner a right of action against the operator for injuries received because of the violation of the statute in failing to properly light a trip of cars.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

FAILURE TO INSPECT MINE—LIABILITY.

In an action by a miner for injuries caused by an explosion of gas, the evidence showed that the injured miner was employed as a shot firer and as he went in the discharge of his duty in a certain part of the mine he encountered standing gas that was ignited and caused to explode by a lamp carried by him, resulting in the injuries complained of. The mine operator employed a fire boss or gas man to inspect the mine for the purpose of ascertaining whether gas had accumulated therein and to report the same and by signs and markings warn the miners of the presence of gas. The inspector entered the mine, as was his custom, at 3.30 a. m. and remained until 11.30 in the performance of such duties and on the day of the explosion his inspection made at 5 o'clock in the morning showed the place to be free of gas. The statute expressly provides that the operator of every coal mine shall provide and maintain ample means of ventilation, affording not less than 150 cubic feet of air per minute for each person employed in the mine, and that the ventilation shall be conducted through the main crossings, entries, and all working places so as to dilute and render harmless and expel therefrom the noxious and poisonous gases and all working places shall be kept clear of standing gas. The statute does not give the mine operator the privilege of reasoning on the sufficiency of appliances for ventilation or leave to his judgment the amount of ventilation that is sufficient for the protection of miners. It expressly provides that all working places shall be kept clear of standing gas. This is an imperative duty and the consequence of neglecting it can not be excused because some workmen may disregard instructions. The statute has prescribed this duty and it can not be omitted and the lives of miners committed to the chance that the care or duty of some one else will counteract the neglect and disregard of the legislative mandate.

McAlester-Edwards Coal Co. v. Hoffer (Oklahoma), 166 Pacific, 740.

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FAILURE TO LIGHT CARS—LIABILITY.

The statute of Illinois (Hurd's Rev. Stats., 1913, chap. 93, sec. 15), requires a mine operator to keep a conspicuous white light on the front and a conspicuous red light or white signal board on the rear of every trip or train of cars run by machinery within the mine. A bottom boss was injured while taking some empty cars through a passageway by being run into by an electric motor that was equipped with a 16-candlepower incandescent electric light upon the motor about 2 feet above the rail and which did not give very much light in front of the motor. In an action by the bottom boss for damages for injuries caused by the collision it was a question of fact for the jury to determine whether the 16-candlepower incandescent electric light was a compliance with the statute requiring a "conspicuous white light."

Daly v. New Staunton Coal Co. (Illinois), 117 Northeastern, 413, p. 416.

FAILURE TO CARRY LIGHT ON CARS—PROXIMATE CAUSE OF INJURY.

The failure of a mine operator to carry a light on the front car of a trip of loaded cars being pushed through a dark entry must be regarded as the proximate cause of an injury to a miner who while passing through the entry at a dark place was struck and injured by the trip of loaded cars.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

FAILURE TO POST RULES—PROXIMATE CAUSE OF DEATH.

The fact that a mine operator failed to promulgate and post rules governing the operations of the mine as required by the statute is immaterial in an action for damages for the death of a miner where the failure to post the rules was not the proximate cause of the miner's death.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 773, p. 776.

FAILURE TO VENTILATE—PROXIMATE CAUSE OF MINER'S DEATH.

The statute of Illinois (Hurd's Revised Statutes, 1915-16, chap. 93, sec. 20), makes it the duty of a mine manager in case of accident by which the ventilation is stopped or obstructed at once to order the withdrawal of all men from the mine and to prohibit their return until the ventilation is restored. The fact that a managing stockholder violated the statute by sending a miner into the mine shortly after an explosion to search for an assistant mine manager and another miner who had gone into the mine to make some investigations, can not be regarded as the proximate cause of the miner's death where later the managing stockholder called the miner while in the mine by telephone and was answered by the miner and then ordered and directed the miner to come out of the mine, informing him that the assistant mine manager and the other miner had returned out of

the mine, and where the miner answered, "All right"; but where the miner with knowledge of the condition of the mine disobeyed the order and went into the dangerous part of the mine where gas had accumulated and was overcome and lost his life.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 773, p. 775.

SAFE WORKING PLACE.

LIABILITY FOR FAILURE.

The statute of Oklahoma imposed upon a mine operator the duty to furnish an employee or miner a reasonably safe place in which to perform his work. This duty ordinarily is absolute and a failure on the part of a mine operator to discharge it constitutes primary negligence; but such a duty is not owing to a foreman employed by the operator and in charge of the work with full authority and charged with the duty of doing all things necessary to make the working place reasonably safe. Whether the person employed was a foreman and was within the exception or whether he was a mere timekeeper and it was not his duty to look after the work of making places safe, are questions of fact and it is for a jury to say what was the real character and nature of the employment and what were his duties at the time of this alleged injury.

Sandals v. Mizpah Min. Co. (Oklahoma), 168 Pacific, 808.

DUTY IMPOSED ON MINER.

KNOWLEDGE OF DEFECTS—DUTY TO INFORM OPERATOR—EXCUSE.

The statute of Alabama (sec. 3910), makes it the duty of a miner to inform the mine operator of any defects or of any negligence that may or probably will result in an injury to the miner. This statute can not be held to mean that it is necessary for a miner to inform the mine operator of any such defect or negligence, where the mine operator or his mine foreman has knowledge of any such defect or negligence. As the law does not require the doing of a useless thing and it would not be necessary for the miner to notify the operator if the operator already knew of the condition and this is true, although the miner may not be aware that the operator knew of the defect.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 78.

VIOLATION BY MINER.

VIOLATION OF STATUTE PREVENTS RECOVERY.

Section 3983-3984, Revised Laws Oklahoma, 1910, applies to mines, and it is the duty of a mine foreman to comply with the law as prescribed by these sections, and a failure upon his part so to do constitutes such negligence as will preclude a recovery in an action by him for injuries.

Sandals v. Mizpah Min. Co. (Oklahoma), 168 Pacific, 808.

EFFECT ON RIGHT TO RECOVER.

The supreme court of Oklahoma approves the general rule that the violation of a statute by an injured person is negligence per se on his part and precludes him from recovering damages. The court strangely says that if it were not for the constitution providing that the defense of contributory negligence shall in all cases be a question of fact left to the jury, a trial court might instruct the jury that the violation of a statute by a plaintiff "was not merely evidence of contributory negligence, but a conclusive bar to his recovery." The court seems to be unable to see, or is at least unwilling to make any distinction between contributory negligence and the violation of a statute. The court does say, in effect, that the doing of a particular act prohibited by statute, or the failure to do an act commanded by statute, on the part of a mine operator, is negligence as a matter of law, or negligence per se, and that this is true irrespective of the question of the exercise of prudence, diligence, care, or skill. But the court refused to apply the same rule to a miner who violated the statute.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1028.

FAILURE OF MINE FOREMAN TO INSPECT—RECOVERY FOR INJURY.

A mine foreman who entered the room and working place of a miner for a purpose other than inspection and without inspecting the same, can not recover damages from the mine operator for injuries caused by a fall of rock, due to the negligence of the miner in the manner of working his room and leaving the roof unpropped. The entering of the room by the mine foreman for the purpose of measuring the gobwork without first inspecting the room, constituted a violation of the statute that would prevent his recovery for the injuries complained of.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1025.

STATUTORY PROTECTION.**PERSONS WITHIN STATUTORY PROTECTION—PLEADING.**

A miner brought suit against a mine operator for damages for injuries due to the alleged negligence of the operator. The action was a common law action for negligence. An answer by the mine operator attempting to show that the injuries complained of resulted from the violation of a statutory duty imposed upon the miner, who at the time he received the injuries complained of was acting as a statutory mine foreman, was insufficient where it failed to show that the mine so operated and in which the injuries were received was within the statutory provision, in that it failed to allege that

there were ten or more persons employed in the mine at the time the complainant was injured. The rule is that a pleading in a statutory action must bring the case within the requirements of the statute, and any omission in this respect can not be supplied by intendment.

Sandals v. Mizpah Min. Co. (Oklahoma), 168 Pacific, 808, p. 809.

EFFECT ON CONTRIBUTORY NEGLIGENCE.

VIOLATION OF STATUTE.

The Virginia mining statutes provides that no person shall under penalty travel on foot to and from his work upon any slope, engine plane, or motor road when other good roads are provided for that purpose. A miner who enters a mine in violation of this statute is guilty of contributory negligence per se and can not recover for an injury occasioned thereby.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 373.

QUESTION OF FACT.

By the constitution of Oklahoma (sec. 6, art. 23), the defense of contributory negligence is a question of fact that shall at all times be left to the jury. The courts are never at liberty to direct a verdict in favor of a defendant on the ground that the plaintiff was guilty of contributory negligence as a matter of law. In all cases whatsoever, contributory negligence must be considered as a question of fact to be left to the jury.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1027.

NO DEFENSE IN CASE OF VIOLATION OF STATUTE.

Under the statute of Illinois contributory negligence of an employee in a coal mine is no defense to an action for damages for an injury received by him by reason of the operator's willful violation of the mining statute.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 733, p. 777.

STATUTORY AND COMMON LAW RULE.

The rule that where a mine foreman or boss is given supervision over a part of the work and is charged with the duty of inspecting the same, and he fails to make such inspection and is injured by the very objects and instrumentalities over which his power extends, obtains in jurisdiction where the general rule as to contributory negligence prevails; but it does not obtain in jurisdictions where the defense of contributory negligence has been abolished by statute.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1027.

MINER'S KNOWLEDGE OF DEFECTS—FAILURE TO INFORM OPERATOR.

The proviso or amendment to section 3910 (Ala. Code, p. 602), is to relieve a miner from the imputation of contributory negligence because of his remaining in the service after knowledge of the defect or negligence on the part of the mine operator, where the miner himself did not commit the negligent act causing the injury and upon whom the duty to remove the defect did not rest; but the amendment does not relieve a miner of the duty to inform the operator or his agent of such defect or negligence when he ascertained such knowledge and when the employer or his agent has no such knowledge.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 76.

See Reynolds v. Woodward Iron Co. (Alabama), 74 Southern, 360.

EFFECT ON ASSUMPTION OF RISK.**BASIS OF DOCTRINE OF ASSUMPTION OF RISK.**

The doctrine of assumption of risk by an employee of the continued negligence of the employer, because such negligence was known to the employee, is a hard one and all statutes looking to relief from it should be liberally construed against it. Penal statutes requiring safeguards for laborers rest on the care of the state for the employee for the sake of himself, of the persons dependent on him, and of the community. The primary and insistent necessity for the enactment of such laws is that men will work in mines and other dangerous places at the constant risk of death or injury whether such precautions are taken for their safety or not.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

QUESTION OF FACT.

The constitution of Oklahoma provides that the defense of assumption of risk shall in all cases be a question of fact and shall at all times be left to a jury. A court can not direct a verdict in favor of a defendant on the ground that the facts conclusively show that the plaintiff assumed the risk. Assumption of risk in all cases whatsoever must be considered as a question of fact to be left to the jury.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024, p. 1027.

OPERATOR'S VIOLATION OF STATUTE—MINER CAN NOT WAIVE.

The violation of a penal statute can not stand on the same legal footing as common law negligence, but renders the mine operator liable to an injured miner, where the injury is the proximate result of the violation of the statute, and it can not be held that a miner assumes the risk of a violation of the statute by the operator though with knowledge of such violation where it is made impossible for him to waive the operator's violation of the statute.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

MINER'S KNOWLEDGE OF DEFECTS—DUTY TO NOTIFY OPERATOR.

The amendment to section 3910 (Ala. Code, p. 602), relieves a miner of the assumption of risk predicated on the fact of his remaining in the employ of the operator after knowledge of a defect or of the operator's negligence, where the miner did not himself commit the negligent act and upon whom the duty to remedy the defect did not rest. But the duty is imposed upon him to give the operator or his managing agent information of any defect or negligence.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 76.

FELLOW SERVANTS.**FELLOW SERVANTS—MINERS WORKING IN SAME PLACE.**

The statute of Utah defines fellow servants as persons engaged in the same grade of service and working together at the same time and place and to a common purpose. This statute must be construed in the light of what the law was on the subject when it was adopted, and when considered in that light the words used must be given their usual and ordinary meaning. It is not necessary that two workmen or miners must work side by side or come in continuous physical contact or touch with each other in order to work at the same place within the meaning of the statute. It would be straining the words of the statute beyond ordinary meaning if it were held that two miners who were working on different levels of a mine are working at the same place within the purview of the statute. Within the meaning of the statute two miners working on different levels in a mine, although working at the same time and to a common purpose, are not fellow servants.

Shields v. Silver King Coalition Mines Co. (Utah), 166 Pacific, 988.

NEGLIGENCE OF FELLOW SERVANT.

An electric motor in a mine was equipped on the front with a 16-candlepower incandescent electric light located about 2 feet above the rail. It also had an arc light located on top of the motor with a reflector that gave a large and brilliant light. The motor driver depended upon this light for lighting up the entry in front of him and it could be turned like a spot light so as to give light in any direction desired, but it gave light only in the direction in which the lens was turned, and when properly turned it would light up an entry or a runaround for a hundred feet so that the motor driver could see objects distinctly that distance in the direction in which the light was turned. The motorman while taking his motor through a run-around negligently failed to turn the arc light so that he could see in the runaround and by reason of this negligence, he ran his motor into and against some empty cars that a bottom man was conducting through the runaround and by reason of which the bottom man was

injured. The mine operator had elected not to accept the provisions of the Illinois workmen's compensation act and for such reason he could not in an action by the injured bottom man set up as a defense the negligence of a fellow servant.

Daly v. New Staunton Coal Co. (Illinois), 117 *Northeastern*, 413, p. 416.

WORKMEN'S COMPENSATION ACT.

CONSTRUCTION—RIGHT OF REVIEW—NOTICE—EXTENSION OF TIME.

The law does not require the Industrial Accident Board to give parties notice of filing an award or require that notice of it be served upon them. The right of parties to file a claim for review expires after seven days from the time of the award and if no claim of review is filed by either party the award stands as the decision of the board. The board may, in exceptional cases and for special reasons, grant an extension of time, but a general rule extending the time for reviewing a claim would be inconsistent with the statute itself. The extension of time is a matter of discretion with the Industrial Board and where the discretion is not abused the courts will not interfere and relieve a party.

Brunette v. Quincy Min. Co. (Utah), 163 *Northwestern*, 1013, p. 1014.

PURPOSE AND CONSTRUCTION.

The purpose of the Iowa workmen's compensation act is that it forms a legislative response to a public demand that a system be afforded whereby employers and employees might escape the evils of personal injury litigation and employees not guilty of willful misconduct might at once receive reasonable compensation for injuries received in their employment, and on the theory that the more hazardous industries would be made to bear the financial losses sustained by the workmen engaged therein through personal injuries. The act should be so construed as to carry out the purposes and objects of the act.

Mitchell v. Phillips Min. Co. (Iowa), 165 *Northwestern*, 108, p. 110.

CONSTRUCTION—ELECTIVE PLAN—COMPENSATORY FEATURES.

The legislature in passing the Iowa workmen's compensation act made it elective rather than compulsory. Under the act an employer was given the right to elect whether he would reject the compensatory features of the law, but if he did so he was deprived of the benefits of certain common law defenses. A radical change was also made with reference to the matter of evidence, and the injured party is not required to do more than prove the injury in the discharge of his duties to make out a *prima facie* case. The legislature did not intend that an employer who rejected the provisions of the act should be

given an advantage thereby over an employer who elected to accept the provisions of the act. The inference is that the legislature intended that an employer rejecting the act should pay damages, and that it should be reasonably certain that an employee could collect them and that these provisions of the act should be an inducement to influence an employer to elect to accept the provisions of the act and pay compensation in accordance with its terms.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 110.

SCOPE OF EMPLOYMENT—RIGHT TO COMPENSATION.

A custom prevailed in a mine by which it was the duty of the men of a shift to drill blasting holes, load them with explosives, and fire the shots at the end of the shift's work. It was a part of the custom for the miners who drilled and loaded the holes and lighted the fuses to wait at a safe distance, listen, and count the explosions to determine if all the shots had exploded. It was also a part of the custom for such miners either to report the missed shots to the superintendent in order to protect the next shift or for one of the departing shift which had fired the shots, to return and investigate and remedy the dangerous situation left by the unexploded charges. But by reason of the smoke, gas, and fumes caused by such explosions the miners wait a reasonable length of time before returning to examine the exploded shots. Under such circumstances a miner who assisted in firing certain shots, after waiting a reasonable time, and who returned, made the investigation and then, some time after his regular quitting hour, left the mine and the premises, was, while so departing from the premises, within the scope of his employment and entitled to compensation for an injury received at such a time.

Atolia Min. Co. v. Industrial Accident Commission (California), 167 Pacific, 148.

EMPLOYER CAN NOT WAIVE COMPLIANCE WITH STATUTE.

A mine operator who elected to reject the provisions of the Iowa workmen's compensation act and who subsequently gave notice to the industrial commissioner of his intention to waive such election and to accept the provisions of the workmen's compensation act, but who failed to post notices of such election on his premises, can not, in a common law action by an injured miner on the ground of negligence avoid liability by showing that the posting of notices on his premises would be useless or futile for the reason that the complainant was an Austrian and could not read the English language.

Paucher v. Enterprise Coal Min. Co. (Iowa), 164 Northwestern, 1035, p. 1037.

REJECTION BY OPERATOR—NEGLIGENCE—PRESUMPTION.

The Iowa workmen's compensation act makes a radical change with reference to the matter of evidence from the common-law rule.

If a mine operator elects to reject the act and a miner in his employ is injured and sues for damages in a common-law action, he is only required by the statute to make out a prima facie case and the act itself places the burden of proof upon the operator and also expressly provides that the employer shall be presumed negligent. The legislature intended, in case the provisions of the act were rejected, that the evidence of an injury should be considered as evidence of negligence and that the fact of negligence might be proved and established by operation of this presumption.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 110.

REJECTION AND ACCEPTANCE OF STATUTE—COMPLIANCE.

A mine operator who rejected the provisions of the workmen's compensation act and subsequently elected to accept its provisions must comply substantially with the statutory requirements under such circumstances and notice must be given to the industrial commissioner and by posting upon the premises, as required by the statute, and the mere tearing down of the former notices and his rejection of the act is not a compliance with the statute.

Paucher v. Enterprise Coal Min. Co. (Iowa), 164 Northwestern, 1035, p. 1036.

REJECTING AFTER ACCEPTING ACT—LIABILITY FOR NEGLIGENCE.

Under the Iowa workmen's compensation act when an employer or employee has elected to reject the terms of the act, such election shall continue until either shall thereafter elect to come under the provisions of the act; but either may at any time after rejecting the provisions of the act elect to accept the provisions of the statute by giving notice as required. The statute also provides that an employer shall be presumed to have elected to pay compensation according to the statute unless notice in writing of an election to the contrary shall be given in the manner provided. In an action by an injured miner against the mine operator for damages, the mine operator can not defeat a recovery on the ground of negligence by showing that he had elected to accept the terms of the workmen's compensation act, where he had properly given notice that he rejected the terms of the statute and subsequently gave notice that he had waived his rejection and had elected to accept the provisions of the statute. The mere filing of a notice by the mine operator with the industrial commissioner of his intention to accept the provisions of the act and waive his former objection and the tearing down the notices posted at the mine rejecting the act without posting notices by his subsequent acceptance of the act, is not a compliance with the statute and is not sufficient to relieve the mine operator from his common-law liability for negligence.

Paucher v. Enterprise Coal Min. Co. (Iowa), 164 Northwestern, 1035.

REJECTION AND ACCEPTANCE—LIABILITY INSURED.

A mine operator who first elected to reject the provisions of the Iowa workmen's compensation act and subsequently elected to waive his former rejection and accept the provisions of the act, must comply substantially with the statute by giving the notices required, and he must also insure his liability under the act in some corporation, association, or organization approved by the State Department of Insurance or be subjected to the liabilities of one having rejected the act.

Paucher v. Enterprise Coal Min. Co. (Iowa), 164 Northwestern, 1035, p. 1037.

ELECTION NOT TO BE BOUND BY—CONTRIBUTORY NEGLIGENCE.

A mine operator who elects not to be bound by the workmen's compensation act of Illinois is prevented by the statute from making any one of the defenses of assumed risk, contributory negligence, or that the injury was caused by the negligence of a fellow servant.

Daly v. New Staunton Coal Co. (Illinois), 117 Northeastern, 413, p. 416.

PROOF OF INJURY—PRESUMPTION OF NEGLIGENCE—BURDEN OF PROOF.

The workmen's compensation act of Iowa provides that in an action by an employee against the employer for damages for personal injuries arising out of and in the course of the employment, where an employer has elected to reject the provisions of the act, it shall be presumed that the injury complained of was the direct result and growing out of the negligence of the employer and that such negligence was the proximate cause of the injury. It also provides that the burden of proof in such cases shall rest upon the employer to rebut the presumption of negligence. Under this provision of the statute, in an action against a coal mine operator for damages for the death of a miner, it is sufficient to make a *prima facie* case, to prove the relation of the deceased to the operator, and that the injuries which resulted in his death were sustained by a fall of slate while in the course of his employment, and that the mine operator had elected to reject the provisions of the statute. When such proof is made, the statute creates the presumption of negligence on the part of the mine operator and that the negligence was the proximate cause of the death of the miner. It is not the office of this presumption created by the statute merely to fix the burden of proof and determine which party shall go forward first with testimony. The mine operator is required to do more than rebut the burden of proof. The effect of the presumption created by the statute is to establish negligence that must be regarded as a fact until contradictory evidence requires a different conclusion. The happening of the accident stands as substantive evidence of negligence on the part of the operator. The presumption arising from proof of the accident is to

be given the effect of affirmative evidence establishing *prima facie* the fact of negligence. In the absence of evidence on the part of the defendant the statutory presumption is to have the force of proof, affording warrant for the passing of judgment. If the mine operator shall proceed with proof the presumption continues having all the force of substantive evidence of negligence until overcome by the weight of affirmative evidence introduced in proof of due care.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 109.

Mitchell v. Des Moines Coal Co. (Iowa), 165 Northwestern, 113.

NEGLIGENCE—PRESUMPTION FROM INJURY—REBUTTABLE.

The Iowa workmen's compensation act makes an injury to a miner in the course of his employment a presumption of negligence on the part of a mine operator who has elected not to accept the provisions of the act. This presumption is rebuttable, and a mine operator may show by evidence that he was not guilty of negligence or that his negligence was not the proximate cause of the injury. The strength of the presumption will depend somewhat upon the facts of each case. The evidence on behalf of a defendant in such a case may be so convincing or undisputable as to show the defendant free from negligence or that the complainant was guilty of willful misconduct or intoxication. Or the physical facts might be such as to preclude a recovery, or it might be possible in case that in proving the accident additional facts might appear which would exonerate the defendant. In any event it is a question for the jury to say whether or not a presumption has been overcome by the defendant's proof.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 110.

See *Mitchell v. Des Moines Coal Co. (Iowa)*, 165 Northwestern, 113.

PRESUMPTION OF NEGLIGENCE—PROOF INSUFFICIENT TO OVERCOME PRESUMPTION.

In an action for the death of a miner caused by injuries received while in the line of his employment, on proof of the fact that the injuries were received in the course of the employment and that the mine operator had not elected to accept the provisions of the Iowa workmen's compensation act, the evidence given by the mine operator in defense of the action must be sufficient to overcome the statutory presumption of negligence on his part.

Mitchell v. Des Moines Coal Co. (Iowa), 165 Northwestern, 113.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108.

PRESUMPTION AS TO DEPENDENCY.

A miner came to this country from Hungary, leaving a wife and one child. He returned to his home once, but contributed substantially to the support of his wife and child and expected to bring them to this country when he had earned sufficient money to pay the

expenses. Under such facts upon his death after seven years from the time he left home the wife is not under the workmen's compensation act of Michigan entitled to the benefit of the conclusive presumption of dependency upon the theory that she lived with her husband at the time of his death.

Kalcic v. Newport Min. Co. (Michigan), 163 Northwestern, 962, p. 963.

WIDOW'S DEPENDENCY—PROOF.

A miner who came to this country from Austria-Hungary and remained here for seven years before his death left a wife and one child in Croatia, but contributed to their support during all the time of his absence and in the last year of his life sent to his wife about \$80. The fact that she by her labor made some trifling earnings, amounting to about 20 cents a day two or three times a month, can not be held sufficient to change her status, and a finding that the widow was totally dependent upon the husband at the time of his death was justified.

Kalcic v. Newport Min. Co. (Michigan), 163 Northwestern, 962, p. 963.

MINER SHOT BY GUARD—RIGHT TO COMPENSATION.

It was the duty of miners working in a mine to drill blasting holes, load them with explosives, and fire the shots at the end of the work of the night shift. It was a part of the duty of the miners to wait and count the shots to see if all exploded, and if not, for one of them to return, after waiting a reasonable time for the smoke, gas, and fumes from the explosion to pass away, and examine as to the unexploded shots. A night shift on quitting the mine at 2 o'clock in the morning loaded and fired the shots and discovered that there were two unexploded shots. One of the miners living near the mine, after waiting a reasonable time, returned in accordance with the duties of the miners to the working place and investigated as to the unexploded shots and thereafter left the mine. The mine operator employed and kept guards around the mine to prevent "high grading" or theft of ores, and while the miner was leaving the mine and walking to his tent he was, without warning and while carrying his light, shot from the rear by one of the guards employed by the mine operator. Under such circumstances it will not be presumed that the guard deliberately perpetrated an assault to commit murder, but it must be assumed that the guard who fired the shot believed that the circumstances justified him in doing so and that he was acting within the line of his employment and that the miner who was shot was injured by the negligent performance of an act within the general scope of the duties of the guard inflicting the injury, and under such circumstances the miner is entitled to compensation under the workmen's compensation act of California.

Atolia Min. Co. v. Industrial Accident Commission (California), 167 Pacific, 148.

EMPLOYER'S LIABILITY ACT.**CONSTRUCTION OF STATUTE—APPLICATION TO CONTRACT.**

The provisions of paragraph 3, section 3, of the employer's liability law (Louisiana Act No. 20, 1914), only applies to contracts of employment that have been in existence more than 30 days. It is inconceivable that a contract of employment made less than 30 days before an accident could contain a notice which would precede the accident by not less than 30 days, as required by the statute. A contract of employment not having been in existence 30 days must be gauged by paragraph 1 and is excluded from the operation of the statute. Such an employee injured while in the employment of an oil company must be remitted in his right to recover damages to article 2315 of the Civil Code.

Woodruff v. Producers' Oil Co., 142 Louisiana, 76 Southern, 803, p. 805.

CONSTITUTIONALITY—RIGHT TO QUESTION.

An employee of an oil company suing for compensation under the employer's liability law (Louisiana Act No. 20, 1914), has no interest while suing under its provisions in attacking its constitutionality.

Woodruff v. Producers' Oil Co., 142 Louisiana, 76 Southern, 803, p. 804.

Wall v. Parrot Silver & Copper Co., 244 U. S., 407, p. 409.

APPLICATION TO MINES.

The employer's liability act of Indiana (Laws, 1911, chap. 74), applies to coal mines and an action may be maintained under that act for injuries arising in coal mines.

Peacock Coal Min. Co. v. Crawford (Indiana Appeals), 117 Northeastern, 504.

Vivian Collieries Co. v. Cahall, 184 Indiana, 473; 110 Northeastern, 672.

Vandalia Coal Co. v. Shephard, (Indiana), 113 Northeastern, 767.

PROXIMATE CAUSE OF INJURY—PLEADING.

A complaint in an action by a miner for damages for injuries received while working in a mine is sufficient under the first subdivision of the employer's liability act (Ala. Code, sec. 3910), where it avers that complainant's injuries were sustained proximately by reason of a defect in the ways, works, machinery, or plant connected with or used in the business of the mine operator and which defect consisted in that the roof of the mine in which plaintiff was working was defective and such defective roof was known to the defendant operator and to the person in charge of the ways, works, machinery and plant and that the operator and the person so in charge knew that if the roof remained in such defective condition, the complainant would likely or probably be killed or seriously

injured in body, but notwithstanding such knowledge the operator and the person so in charge grossly, wantonly, and recklessly permitted the roof to remain in such defective condition and the complainant was proximately injured from such gross and wanton negligence.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 76.

See *Clinton Min. Co. v. Bradford*, 192 Alabama, 576; 69, Southern, 4.

STATUTORY ACTION FOR WRONGFUL DEATH.

RIGHT OF WIDOW TO SUE.

The statute of Kentucky authorizes an administrator to maintain an action for the wrongful death of a miner. But where the administrator refuses to bring suit the widow of the deceased miner may maintain the action.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075.

ARTESIAN WELLS.

CONSTRUCTION, VALIDITY, AND EFFECT OF STATUTE.

The purpose of the statute of New Mexico (secs. 265-268, Code 1915), authorizing the artesian well supervisor to enter upon the land of a private person and stop the flow or waste of artesian water is a valid exercise of the police power of the State. The making of the repairs on the well as provided by the statute or the preventing of waste is not for the benefit of the owner of the land upon which the well is located which may be wasting water, but is for the purpose of abating a public nuisance. The statute authorizes the well supervisor to make the repairs or to plug the well in case the owner fails to do so after notice. The legislature evidently was of the opinion that this provision was necessary in order to conserve the artesian waters of the State for the purpose of irrigation and other beneficial uses; and it is competent for the legislature to conserve the natural resources of the State. The artesian waters in a given district come from the same source and are obtained by sinking wells to the common basis, thereby enabling the water to find its way to the surface. Naturally the waste of water derived from the common source or supply diminishes the amount of water available for legitimate uses, and therefore works an injury and a detriment to the general public desiring to make use of such waters.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 728.

WELL SUPERVISOR—DUTY TO STOP FLOW.

Section 265 of the Statute of New Mexico (Code, 1915), authorizes the artesian well supervisor where the water of an artesian well is suffered or permitted by the owner unnecessarily to flow or to go

to waste, to notify in writing such owner to make diligent efforts to have such flow of water stopped within 30 days. On the failure of such owner to take such steps it is made the duty of the artesian-well supervisor to cause the necessary repairs to be made or take whatever steps necessary to stop the flow of waste water by plugging the well. The statute does not contemplate that the well supervisor shall undertake at great expense to repair a well so as to continue the flow for the use of the owner when the waste might be limited at a small expense by plugging the well. The supervisor is the representative of the public or the water consumers of the district and the public has no concern with the question as to whether or not the owner of the land shall continue to use water from the well. If he fails on proper notice to repair the well, the public interest demands only the abatement of the nuisance by stopping the waste of water, and if this can be done by plugging the well at a trifling expense, whereas to repair the well would entail a large expense, it is the duty of the well supervisor to adopt the least expensive and the most efficacious method, as the public is interested only in preventing the waste of water. But the method and means to be adopted to abate the nuisance is placed by the statute in the discretion of the well supervisor, and in the absence of a showing of gross abuse of such discretion the courts will not interfere.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 730.

FLOWING ARTESIAN WELLS—NUISANCE.

The statute of New Mexico (sec. 265-268, Code, 1915), provides for the summary abatement of a public nuisance created by an artesian well that has been permitted by the owner to be and remain out of repair so that water is unnecessarily permitted to flow to waste and authorizing the artesian well supervisor, created by statute, to enter upon the premises and repair or plug the well, is a valid exercise of the police powers of the State and is not violative of either the constitution of the State or of the United States.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 727.

ABATEMENT OF NUISANCE—ENTRY ON LAND.

The artesian well supervisor is by section 265 (Code New Mexico, 1915), authorized to enter upon the lands and premises of the owner of an artesian well who fails on notice to stop the flow and waste of water from such well, and himself repair or plug the well. Under such authority the officer is authorized to enter upon the lands of the guilty party, provided he can do so in a peaceable manner and remove or abate the nuisance, doing no greater injury than is necessary to accomplish the abatement of the nuisance.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 726.

MINES AND MINING OPERATIONS.

RELATION OF MASTER AND SERVANT.

WHAT CONSTITUTES STATUS.

One who represents and carries out the will of the master or of a mine operator in the prosecution of the work not only as to the result to be accomplished but also as to the means to be employed, is a servant and not an independent contractor.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 79.

PROOF OF RELATION OR STATUS.

There is no error in permitting an injured employee to testify that he worked for the mine operator, especially where this is merely introductory to the evidence that was to follow and where there was no attempt to impeach or to corroborate or to contradict his testimony.

Empire Coal Co. v. Goodhue (Alabama), 76 Southern, 31, p. 32.

EXISTENCE OF RELATION—TERMINATION OF RELATION.

The relation of master and servant existing between a coal mine operator and his miners continues to exist until the miners who are hauled out of the mine on an electric car are taken to the surface of the mine, depart from the car, and are no longer under the control of the operator or amenable to his rules and regulations.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 101.

EXISTENCE OF RELATION—PROOF OF NEGLIGENCE.

Where the relation of master and servant is an issue in any case it may be proved by the circumstances of the employment, and it is sufficient where the employee testifies that he was employed by agents of the employer and that one of such agents refused, after his injury, to pay him his wages unless he would sign a receipt.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021.

ACTIONS—PLEADING AND PROOF OF NEGLIGENCE.

PLEADING NEGLIGENCE—SUFFICIENCY OF COMPLAINT.

A complaint in an action by a miner for damages for injuries averred that a coal mine operator, the defendant, negligently failed and omitted to keep the working place in the mine where the com-

plainant was assigned to work and the roof thereof in a reasonably safe condition, and carelessly and negligently permitted the roof to become weak, unsafe, and dangerous continuously for three days; that with knowledge of such weak, unsafe, and dangerous condition of the roof the operator negligently failed and omitted to take down and remove therefrom certain loose slate and rock which during such time was in the roof, and negligently failed and omitted otherwise to make the roof reasonably safe and secure; that with knowledge of such dangerous conditions the operator negligently and carelessly directed the complainant to enter said room for the purpose of mining coal therein; that the complainant did not at any time prior to his injury have any notice or knowledge of such weak, unsafe, or dangerous condition of the roof, but in obedience to such orders, and believing the room and roof thereof to be safe, entered the same and began mining coal under his employment; that while so engaged and within a few minutes after entering the room the roof suddenly and without warning gave way and large quantities of loose rock and slate fell upon and injured the complainant. It is also averred that during all the time the operator employed in said mine more than five persons, to wit, 25 persons. These averments clearly show that the pleading is based on a violation of the common-law duty of the mine operator to keep the miner's working place reasonably safe, and is sufficient upon that theory.

Peacock Coal Min. Co. v. Crawford (Indiana Appeals), 117 Northeastern, 504.

In an action for damages for the death of a miner the complaint or declaration is sufficient which alleges that the death proximately resulted from the negligence of an employee who was also in the employ of the defendant mine operator, who had superintendence intrusted to him by the operator, while in the exercise of such superintendence, and that the negligence of said superintendent consisted in this: That the said employee who had superintendence of a certain steam shovel used in mining ore and the man who worked on or about the same negligently allowed said steam shovel to be operated in a manner dangerous to the safety of the intestate, whereby the dipper attached to such steam shovel fell upon and killed the miner.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47.

PERSONAL INJURIES—SUFFICIENCY OF COMPLAINT.

A miner suing for damages for injuries alleged in substance: (1) Defendant's corporate capacity; (2) its ownership of the mine; (3) the employment of the plaintiff; (4) his place of work; (5) the location of a shaft in which the cage was operated; (6) its relation to the plaintiff's place of work; (7) the purpose of the cage; (8) the manner of its operation by the engineer; (9) the employment of the

engineer; (10) his duties in respect to the cage and the persons being carried therein; (11) the carelessness of the mine operator in failing to employ a competent engineer; and finally the carelessness and negligence of both the engineer and the company in operating the cage while attempting to convey plaintiff to his place of work, together with the consequential injury to him and the damages sustained by him. A plaintiff may be charged with as many acts or omissions constituting negligence as the circumstances warrant and he may rely upon one or all according to the effect, without being subject to the charge of switching from one theory to another. While the complaint may not be perfect in form as against hypercritical objectors, not a single element of a good complaint is omitted.

Farnon v. Silver King Coalition Mines Co. (Utah), 167 Pacific, 677.

PLEADING AND PROOF.

In an action by a miner for damages for injuries caused by falling slate he averred in his petition that the mine operator in violation of his duty failed to prop or to maintain the roof of the entries in the mine so as to make them reasonably safe for the use of the employees passing into and out of the mine; and that the mine operator negligently ordered and directed the injured miner to perform his work in the place where the accident occurred. Under such allegations of negligence, it is not proper to make proof of negligence on the part of the mine operator in failing to furnish the miner props for his use in propping the roof of the mine. Under the allegation of the failure of a mine operator itself to prop the roof where the injured miner was working and of the operator's failure to furnish the miner a reasonably safe place to work, evidence of the operator's failure to furnish the miner sufficient props to support the roof is not admissible. In such a case the proof of negligence must follow strictly the allegations of the pleading and it is not permissible to make proof of acts of negligence outside of the issues framed by the pleading.

Stearns Coal & Lumber Co. v. Gaines (Kentucky), 197 Southwestern, 927, p. 928.

PLEADING AND PROOF—PROXIMATE CAUSE.

In an action for the death of a miner the complaint alleged that the deceased was injured in a mine by the explosion of gas; that he lived for a period of 11 days thereafter, and then died from the effects of the injury received in the explosion. To justify a recovery the jury must find from the preponderance of the evidence that the death of the deceased was the direct or proximate result and that the injuries alleged to have been received in the explosion were caused by the negligence of the mine operator as alleged in the complaint.

Sterling Anthracite Coal Co. v. Strobe (Arkansas), 197 Southwestern, 853, p. 859.

PROOF OF NEGLIGENCE—QUESTION OF FACT.

In an action by a miner for damages for injuries on the ground of negligence, the question of whether a wheel 16 feet in diameter and weighing about 9,000 pounds could be safely lifted by three jacks that were being used by a crowbar, a piece of pipe, and a wooded forge for handles, instead of the proper handles, and whether such jacks were sufficient to perform the work and were properly equipped and reasonably safe for the work, are questions of fact to be determined by the jury trying the case.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021.

PRESUMPTION OF NEGLIGENCE.

The universal rule is that negligence must be proved and that it may not be inferred from the mere fact of an accident. But the law recognizes certain legal presumptions from particular facts in certain classes of cases which are entitled to consideration. Where the machinery and appliances, the giving away of which admittedly caused an injury, are under the exclusive control of the employer, a mine operator, and over which the injured employee has no control and nothing whatever to do with the construction or repair thereof, then the doctrine of *res ipsa loquitur* applies and a legal presumption of negligence arises that must be met and overcome by proof of want of negligence.

Velotta v. Yampa Valley Coal Co. (Colorado), 167 Pacific, 971, p. 973.

NEGLECTANCE PRESUMED—PRIMA FACIE EVIDENCE.

Negligence may be presumed where an injury was caused by an act which in the ordinary course of things would not have resulted in injury if due care had been used in its performance. Where an employer owes to an employee a duty to use care and the thing causing an accident is shown to be under the management of the employer or his servants and the accident is such that in the ordinary course of things does not occur if those who have the management or control used proper care, the happening of the accident in the absence of evidence to the contrary is evidence that it arose from the lack of requisite care. But under such circumstances the happening of the accident is merely *prima facie* evidence and not conclusive proof of negligence. If the physical facts of an accident themselves create a reasonable probability that it resulted from negligence, the physical facts are themselves evidential and furnish what the law terms "evidence of negligence" in conformity with the maxim *res ipsa loquitur*.

Velotta v. Yampa Valley Coal Co. (Colorado), 167 Pacific, 971, p. 974.

PROOF OF NEGLIGENCE—PRIMA-FACIE CASE.

The doctrine of *res ipso loquitar* applies in cases of master and servant in a more restricted sense than in the case of carrier and passenger. The mere breaking of a piece of machinery or of a dangerous live electric wire is not sufficient evidence of negligence to make it a prima-facie case against a mine operator. But where an accident and resulting injuries are caused from defective conditions which can be explained on no reasonable hypotheses other than negligence, even slight circumstances, independent of the accident itself, which tend to show negligence on the part of the master will be sufficient to authorize the submission of a case to the jury.

West Kentucky Coal Co. v. Key (Kentucky), 198 Southwestern, 724, p. 726.

BURDEN OF PROOF ON EMPLOYER—PRESUMPTION OF NEGLIGENCE.

When the thing or machinery or appliance causing an injury is under the management of the employer, and the accident is such as ordinarily does not happen if those having the management used proper care, a presumption of negligence arises from the happening of the accident. The reason for the rule is that all information as to the construction and working of the machinery and of the particular equipment in fault is in possession of the employer, as are all means of rebutting the charge of such negligence entirely within his power. An outsider can hardly be expected to prove that in the construction of the machinery or in the use of it at the time an injury occurred the employer was guilty of negligence. The injured person can only prove that the injury occurred through the operation of the employer's machinery, and having done this it is but proper to call on the employer to show that he was not negligent, that he employed careful and competent servants, and that he used improved appliances, or that there was no negligence in operation.

Velotta v. Yampa Valley Coal Co. (Colorado), 167 Pacific, 971, p. 974.

PROOF—EXPERIMENTS ON INJURED PERSON.

An electrician was employed by a coal mine operator whose duties were to look after, repair, and keep properly equipped the electric wires used in and about the coal operator's mines for illuminating purposes and for furnishing motor power to the machinery. The electrician while in the line of his duty and upon one of the poles carrying both illuminant and power wires came in contact with wires conducting the power for motor purposes and sustained a shock and slight burns. In an action for damages on the grounds of negligence the court properly refused to permit an expert electrician while giving his testimony to make an experiment upon the body of

the complainant and show that the volume of electricity which the evidence showed was passing through the wires with which the complainant came in contact at the time of the accident could be withstood by the complainant without any injurious result. Parties litigant may be subjected to physical examinations and within reasonable bounds tests may be made for the purpose of demonstrating the truth or falsity of an issue made in a particular case, but in the particular case it was the very contention of the complainant that the injuries did result, and a recovery for which he sued; and the trial court could not compel the complainant to submit to the test to determine whether the same injuries would or would not again result.

Stearns Coal & Lumber Co. v. Williams (Kentucky), 198 Southwestern, 54, p. 56.

PROOF INSUFFICIENT TO ESTABLISH.

A car of loaded coal was derailed on an incline in the mine but was held in position by a cable or chain attached to the car by a hook. Another car loaded with coal was standing at the safety catch at the bottom of the incline and a few feet below the place where the first car was derailed. Some miners and a boss carpenter, a part of whose duty it was to inspect and keep in repair the particular place, attempted to replace the derailed car upon the tracks and while so engaged the hook on the cable or chain in some unknown way became detached and the car ran back down the incline, caught the carpenter between it and the loaded car standing at the safety catch, causing injuries from which he died. In an action for damages for the death of the carpenter the proof of the facts and circumstances were not sufficient to show that the mine operator was guilty of any actionable negligence, and that the particular accident occurring in the peculiar manner in which it did could not have been reasonably expected and provided against.

McMennimen v. Lehigh Valley Coal Co. (Pennsylvania), 101 Atlantic, 735, p. 736.

NEGLIGENCE OF OPERATOR.

PROXIMATE CAUSE—QUESTION OF FACT.

Where negligence on the part of a mine operator is shown, whether the intervening negligence of the person injured is a proximate cause of the injury is a mixed question of law and fact, and is therefore primarily one for a jury to determine upon proper instructions. A court can not undertake to settle it in any case where it involves the weighing of conflicting evidence, the balancing of probabilities, and the drawing of inferences.

Oklahoma Coal Co. v. Corrigan (Oklahoma), 168 Pacific, 1024.

PROXIMATE CAUSE OF INJURY.

The failure of a coal mining company to use ordinary care to keep the roof of an entry safe can not be said to be the proximate cause of the death of a miner who left his working place and went to the working place of another miner to obtain some information and while in the working place of the other miner was killed by a fall of rock from the roof.

Hyden v. Stearns Lumber & Coal Co. (Kentucky), 198 Southwestern, 775.

PROXIMATE CAUSE OF INJURY—INTERVENING AGENCY.

A miner was directed by the mine foreman to repair the track at a particular point where the rails had spread, thereby causing the mine cars to become derailed. While so engaged a miner pushed a loaded car down the track and the car was derailed. The track repairer while assisting to place the loaded car back on the tracks was injured by a trip of empty cars that was pushed into the entry where the work was being done. The entry was not lighted and there was no light upon the front of the trip of empty cars and the lights on the miners' caps were insufficient to permit them to see the trip of empty cars. The miner had just been assigned to the duty of repairing the track and had been given no warning as to the empty cars being pushed in. The loaded car under such circumstances can not be regarded as an intervening agency or the superseding cause of the miner's injury. A superseding cause must entirely supersede the operation of the negligence of the mine operator so that such cause alone without the operator's negligence contributing in the slightest degree thereto did in fact produce the injury.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

CONCURRING CAUSES—LIABILITY.

Where two concurring causes produce an injury that would not have resulted in the absence of either, the party responsible for either cause is liable for the resulting injury.

Sterling Anthracite Coal Co. v. Strobe (Arkansas), 197 Southwestern, 858, p. 859.

NEGLECTANCE NOT PRESUMED FROM INJURY.

In an action for the death of a miner caused by an explosion of gas, the jury can not presume or infer negligence alone from the condition of the mine or the accident itself, or both. Proof that the working place of the miner was filled with gas and an explosion followed causing the death of a miner would not justify a recovery without proof that the condition was caused by the negligence of the mine operator.

Sterling Anthracite Coal Co. v. Strobe (Arkansas), 197 Southwestern, 858, p. 859.

NO DUTY OWING.

A mine operator can not be charged with negligence where the miner was injured while taking down slate and where he himself was charged with the duty of taking down the slate for his own protection and where the perils to which he was subjected were of his own creation, as in such case, the mine operator owes the miner no duty to use ordinary care to furnish him a reasonably safe place for work.

Gregg v. Stonega Coke & Coal Co. (Kentucky), 198 Southwestern, 5.

PERSONAL INJURIES—DISEASE SUPERVENING—LIABILITY.

A miner was severely and dangerously burned by an explosion of gas in his working place, although the mine inspector had reported the miner's working place as free from gas. The miner was burned on both arms, across the chest and neck, and all of his face and back of the neck and on his back lower than the shoulder blades, and all the skin on both arms came off. By reason of these injuries the miner, a young man of 31 years of age and otherwise an exceedingly stout and healthy man, was compelled to lie on his back and could not turn over, and on the day of his death, he developed hypostatic pneumonia. This was a secondary condition which might develop after any serious injury that necessitates the patient staying in bed. The evidence of a medical expert showed that if a person is burned over the chest he is more likely to have pneumonia and that the burns and the necessary recumbent position caused the pneumonia. It was sufficient to create a liability on the part of the mine operator on the ground of negligence in the matter of inspection where it appeared that the miner died from pneumonia and the pneumonia was wholly or in part caused or superinduced by the burns, as the death was in law caused by the burns on the theory that where two concurring causes produce a death, that would not have resulted in the absence of either, the party responsible for either cause is liable for the resulting injury.

Sterling Anthracite Coal Co. v. Strobe (Arkansas), 197 Southwestern, 858. p. 859.

FAILURE TO INSPECT—NEGLIGENCE OF FIRE BOSS.

The fire boss of a mine operator inspected the mine and the working places for gas in the morning before the miners began work. After finishing his inspection, he returned to the entry of the mine and marked the working places "O K," which meant that they were free from gas and safe for the miners to commence work. It was the duty of the fire boss to make the inspection and if the working places contained no gas to so mark them on the board. A miner seeing the board so marked proceeded into the mine and when near the face of his working place lit his lamp and placed it on his cap and thereupon

there was an explosion of gas by which the miner was severely injured and died 11 days thereafter. The negligence of the fire boss in failing to make a proper inspection and to discover the presence of gas was the negligence of the operator and rendered him liable for the death of the miner.

Sterling Anthracite Coal Co. v. Strops (Arkansas), 197 Southwestern, 858.

LIABILITY FOR DEATH OF BOY.

A boy 15 years old was employed by a coal mine operator to attend a switch and when necessary to oil the sheave wheels over which a cable ran and to keep the tracks clear of coal. When not actually engaged in these duties he was required to remain on the concave side of the tracks over which cars were taken in and out of the mine. The cars were drawn up and down an incline by a cable that was held in place while passing around the curve in the track by sheave wheels or grooved pulleys attached to the track or crossties at stated distances and over and around which the cable ran, to keep it parallel and to curve with the track. When the boy was last seen before injured he was standing at his proper position on the convex side and at the center of the arc made by the curve in the track; when next seen or found he was injured, both legs broken and with a severe scalp wound, and unconscious and died shortly after. At the time the boy was discovered in the injured condition the cable was free from the sheave wheels, some of them broken and one at least torn loose from the track and hurled a great distance and the cable was released from its curved position and was drawn straight across and some distance from the track at the boy's position, forming in effect a chord of the arc described by the track. At the trial of the case for damages for the death of the boy no witness could testify as to the actual occurrence but it was sufficient to make a *prima facie* case and to raise the presumption of negligence to prove that the track and cable and sheave wheels and all the appliances were prepared and maintained by and were under the control of the mine operator and that the boy had no control or management of or authority over any of the appliances or the method of their operation and to establish the conditions as they existed at the time the body of the injured boy was discovered.

Velotta v. Yampa Valley Coal Co. (Colorado), 167 Pacific, 971, p. 972.

FAILURE TO FURNISH PROPS—PROXIMATE CAUSE OF INJURY—QUESTION OF FACT.

The question of whether or not the negligence of a mine operator in failing to furnish props upon request by a miner was the proximate cause of the miner's death is one of fact to be determined by the jury.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 Southwestern, 633, p. 634.

FAILURE TO PROVIDE SAFETY HOLE.

The failure of a mine operator to provide a safety hole in an entry in which a miner may enter to give signals may constitute actionable negligence where a miner was killed by a runaway car while attempting to ring a bell used to signal the engineer in charge of the cars, and where such signal bell was in the entry located near the tracks.

Ford v. Lehigh & Wilkes-Barre Coal Co. (Pennsylvania), 101 Atlantic, 958.

OPERATIONS OF CAGE BY ENGINEER—NEGLIGENCE—QUESTION OF LAW.

The duty of a hoisting engineer employed by a mine operator was to operate a cage for the purpose of carrying men and material to and from the lower workings of the mine. He could keep control of the cage by properly using the brake and clutch, but by inattention to these simple details disaster might result. His mind was not engrossed by attention to other duties and his position was one of grave responsibility, although the duties pertaining to it were so simple and free from complications as to render it almost impossible to fail in the proper performance of them except through the want of such care as would constitute negligence. And where a miner entered the cage to be lowered into the mine and the signal to lower was given the engineer in the usual manner, the engineer released the brake or failed to set the clutch and the cage dropped to a depth of 110 feet with such force as to smash the bulkhead and injure the miner. Such conduct is negligence per se.

Farnon v. Silver King Coalition Mines Co. (Utah), 167 Pacific, 677.

PROXIMATE CAUSE OF DEATH OF MINER.

An explosion of gas occurred in a mine when all the employees except two shot firers were on their way out of the mine. After the miners were out of the mine, the assistant mine manager together with one other miner went back into the mine to investigate the cause of the explosion. While these two men were in the mine, a stockholder of the mining company learned that the assistant mine manager and one miner had gone into the mine and he thereupon sent a third miner, who took with him a companion, into the mine to find and bring back the assistant mine manager and the miner who had gone with him. The stockholder later having learned that the assistant mine manager and the other miner had come out of the mine by a different shaft thereupon called by telephone the miner who had gone in search of the assistant mine manager and the other miner, informed him that the two men were out of the mine and positively ordered him to come out and told him he could do no good in the mine. The miner answered: "All right." The miner said to his com-

panion that he was going on anyway and see if he could not save the two shot firers. He knew that the air was bad and his companion did all he could by way of persuasion to induce him to return out of the mine; he positively refused to do so saying that he understood the mine and that when he rested and got his wind he could go on. The miner was finally overcome and fell and his companion attempted to drag him along but was too weak himself. This companion was later overcome and was found unconscious by the rescue party and his life saved. The miner sent in by the stockholder was found dead. Under such circumstances it can not be said that the violation of the statute on the part of the mine operator was the proximate cause of the death of this miner; but the proximate cause of his death was his willful violation of the positive order of the stockholder to return out of the mine. This direction and command was given him at a time when he was in a safe part of the mine and when by obeying the order his life would have been saved.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 773, p. 775.

DUTY OF OPERATOR TO FURNISH SAFE PLACE.

DEGREE OF CARE REQUIRED.

A mine owner and operator is not an insurer of the safety of a miner, but the operator owes him the duty of exercising ordinary care to provide him a safe place in which to perform his duties, and this includes the entry ways in the mine to the miner's place of work and the use of care to keep such entryways free from dangerous accumulations of gas. This duty to use ordinary care to provide the miner a safe working place includes the duty of reasonable inspection of the mine, its entries, rooms, and working places and of using such means as ordinary prudence dictates as proper to safeguard the lives and limbs of its employees. The failure to exercise such care and to perform such duty constitutes negligence on the part of the mine operator.

Sterling Anthracite Coal Co. v. Strobe (Arkansas), 197 Southwestern, 858, p. 859.

EXERCISE OF CARE.

A mine operator is not required to use more than ordinary care and diligence to provide his miners reasonably safe ways of ingress and egress to and from their work.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 102.

DUTY NONASSIGNABLE—LIABILITY OF OPERATOR.

It is the duty of a mine operator to exercise reasonable care to furnish his miners a safe working place and this duty is nonassignable. In principle it is not from the difference in the character of

the service that such nonassignable duty arises, but from the situation and surrounding circumstances in which the miner is placed and the knowledge, actual or constructive, of these factors in the case being brought home to the employer.

Clinchfield Coal Corp. v. Ray (Virginia, 93 Southeastern, 601, p. 604.

MINER'S RELIANCE ON EMPLOYER'S PERFORMANCE OF DUTY.

It is the duty of a coal-mine operator to furnish a safe place for a machine operator and his helper in which to operate a coal-cutting machine. Neither the operator of the machine nor his helper is required to discover hidden dangers, but each has a right to rely upon the operator discharging his duty to him. The law in such case imposes upon the machine helper no duty of inspection, the limitation being that a miner can not brave obvious dangers and then hold the operator responsible. Under this rule, a mine operator is liable for injuries to a machine operator's helper where such injuries were caused by a fall of slate from the roof of that part of a room where the machine operator and his helper were not required to inspect or keep safe.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 562.

DUTY OWING TO SUBCONTRACTOR.

A mine operator entered into a contract with a third person to mine a stated amount of coal at a stated price per ton and by the terms of the contract the contractor was to prop the roof and take down the draw slate. Under this contract, the mine operator did not owe a miner employed by the contractor the duty to prop and take down draw slate. By contract the contractor, the employer of the miner, had agreed and assumed the duty to prop and take down draw slate, and the mine operator can not be held liable for failing to furnish the miner a safe place in which to work.

Lyttle v. Rex Coal Co. (Kentucky), 197 Southwestern, 1070, p. 1071.

PROOF OF CONDITIONS IN OTHER PARTS OF MINE.

In an action for the death of a miner caused by the alleged negligence of the mine operator in failing to provide the miner with a safe place in which to work and where the evidence showed that the negligence consisted in the operator using bad timbers, it is not proper to admit evidence as to the condition of the mine at other places and of the timbers at other places in the mine. But any such error is cured by an instruction by the court that the condition of the mine at any other place than that of the accident was wholly immaterial and irrelevant.

Empire Coal Co. v. Goodhue (Alabama), 76 Southern, 31, p. 32.

DUTY TO PROP ROOF—PROOF OF CUSTOM.

As a miner progresses in the work of mining and advances his room, the question may arise as to what part of the room is a miner's working place and as to when his duty to timber ceases and when the operator's duty to timber begins. In an action for the death of a miner caused by a fall of slate where the roof of the room had become dangerous and was known by the foreman of the mine to be dangerous, where there is any doubt or question as to the miner's working place, and where neither the law nor the contract fixes his working place, it is proper to prove a custom in the mine to the effect that it was a custom of the mine operator under such circumstances to place cross timbers over the place where the slate fell or to take down the defective roof, and especially where, as in this instance, there was a slip in the roof. Proof of custom was competent to show that it was the duty of the mine operator under the circumstances shown to look after the roof at the particular place in controversy.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 110.

SIGNAL BELL IN ENTRY.

A mine operator maintained in an entry and near the mine tracks a signal bell so that miners could signal the engineer in charge of the cars. A miner while attempting to give a signal to the engineer was struck by a loaded car that became detached and ran down the slope jumping the track near where the miner was standing, causing injuries from which he died. The mine operator was negligent in not providing a safety hole for the signal where miners might stand while giving a signal.

Ford v. Lehigh & Wilkes-Barre Coal Co. (Pennsylvania), 101 Atlantic, 958.

DUTY TO PROVIDE SAFE APPLIANCES.**USE OF BEST POSSIBLE APPLIANCES NOT REQUIRED.**

An employer as a mine operator is not required to use the best possible appliances in his mining operations, but in an action for damages for injuries caused by defective appliances he may show that the appliances adopted and used by him are such as are employed by many prudent persons engaged in the same business under like circumstances; but such proof, however, does not necessarily exempt an operator from liability. A prudent person may do imprudent things and fail to use proper appliances in the conduct of this business and for such neglect and failure in a proper case, he would be liable to those to whom the duty of prudence and care is due for injuries proximately resulting from such neglect and failure.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47, p. 48.

USE OF ORDINARY CARE.

The employer's duty to his employees is performed by using ordinary care for their safety in the matter of furnishing appliances, and ordinary care when applied to the duty of an employer is that degree of care which ordinarily prudent and careful persons would exercise under the same or similar circumstances. The greater the danger the greater the degree of care required to constitute ordinary care.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

EMPLOYEES KNOWLEDGE OF DEFECT—RECOVERY FOR INJURY.

A miner was furnished a coal-cutting machine that was defective and out of repair. He knew as well or better than anyone else the condition of the machine he was required to operate, knew that it was out of repair and that when being operated the whole machine would quiver, shake, and jump to such an extent that the rear jack had frequently fallen, and was injured because of the shaking and jumping of the machine. Under such circumstances he can not recover damages for injuries received.

Stonega Coke & Coal Co. v. Bush (Kentucky), 197 Southwestern, 389, p. 390.

ELECTRICAL APPLIANCES.**DUTY TO USE REASONABLE CARE.**

It is the duty of a mine operator to use reasonable care to maintain electric wires used in a haulageway in a safe position.

Virginia Iron, Coal & Coke Co. v. Prophet (Virginia), 93 Southeastern, 590, p. 591.

DUTY AND LIABILITY OF MINE OPERATOR.

In an action for damages for the death of a miner caused by a sagging electric wire it appeared that the attention of the mine boss in charge of the entry had been specifically directed to the sagging and dangerous condition of an electric live wire four or five days prior to an accident. Under such circumstances, it is a question of fact for the jury to determine whether the mine operator was negligent in failing to remedy the dangerous condition of the wire.

Virginia Iron, Coal & Coke Co. v. Prophet (Virginia), 93 Southeastern, 590, p. 591.

LIABILITY FOR INJURIES—QUESTION OF FACT.

In an action for damages for the death of a miner caused by a live electric wire used in a haulageway the jury is justified in finding the mine operator guilty of negligence in permitting a live electric wire to swing down and hang some 2 feet below its proper position because of the insulators becoming detached, with a knowledge of the dangerous situation and where the attention of the mine boss in charge of the entry had been called to the condition of the wire four or five days prior to the time of the accident.

Virginia Iron, Coal & Coke Co. v. Prophet (Virginia), 93 Southeastern, 590, p. 591.

CARE AS TO USE OF ELECTRIC WIRE.

The omission of a mine operator to use ordinary care to make a fallen electric wire reasonably safe, after knowledge of its unsafe condition, or who by ordinary care might have known of the defective condition, is negligence.

Virginia Iron, Coal & Coke Co. v. Prophet (Virginia), 93 Southeastern, 590, p. 591.

DEGREE OF CARE REQUIRED BY EMPLOYER.

Ordinary care exercised by mine operators and others who make a business of using electricity for a profit to prevent injury to employees and others therefrom requires much greater precaution in its use than where the element used is of a less dangerous character. As there is greater danger and hazard in the use of electricity, there must be a corresponding exercise of skill and attention for the purpose of avoiding injury to another, to constitute what the law terms ordinary care. The care must be commensurate with the danger. But as a matter of law a mine operator using electricity is not bound to exercise the greatest care and prudence to prevent injury to his employees, as this would impose upon an employer a higher degree of care than that described and defined as "ordinary care."

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

When a mine operator is using in the conduct of his business an agency so subtle and deadly as electricity in places where miners have the right to go and be, the highest degree of skill and care attainable should be exercised to protect the miners from danger.

West Kentucky Coal Co. v. Key (Kentucky), 198 Southwestern, 724, p. 727.

DEGREE OF CARE REQUIRED—CONSTRUCTION AND MAINTENANCE.

It is the duty of a coal-mine operator, where it uses electrical appliances in its coal mines and its wires carry a deadly or dangerous current of electricity, to use the utmost care and skill in the construction, management, and maintenance thereof; and it is its duty to exercise and use the utmost care and skill to properly support such wires and to keep them in repair. The duty as to the proper construction is as necessary to their safety as to their maintenance after construction.

West Kentucky Coal Co. v. Key (Kentucky), 198 Southwestern, 724, p. 726.

LIVE ELECTRIC WIRE—LIABILITY FOR INJURY FROM.

A coal-mining company maintained an electric railway over which its miners were transported from their working places to the main slope leading to the surface. The entry or tunnel through which the electric railway passed varied with the height or thickness of the seam of coal, but there were few if any places where the distance between the floor and roof was less than 6 feet. The trolley wire

feeding the motor was maintained about 5 feet 7 inches above the track and 14 inches horizontally outside of and away from the tracks. It was impractical to increase the height of the entry by breaking the roof as it existed at the time the coal was mined and removed therefrom, as this would create an additional element of danger. The mining company is not to be charged with negligence in maintaining the live trolley wire at the height of 5 feet 7 inches above the track where it would produce a more dangerous situation to break the roof in order to have the wire at a greater distance from the floor of the entry.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 101.

BREAKING OF ELECTRIC FEED WIRE—LIABILITY OF OPERATOR.

A trip rider employed by a mine operator while riding on a trip of cars and seated on an electric motor was, by reason of the breaking and sagging of the feed wire, caught by the wire and thrown under the motor and received injuries for which he sued. The wire and hanger supporting it had been in use for many years, and there was a bright spot near the place where the wire broke which indicated a worn condition. It did not appear that any minute examination or inspection of either the wire or hanger was ever made or that either was ever subjected to any test. Both the wire and hanger were subjected many years to the constant friction from the trolley wheel, and there was evidence tending to show that the worn condition of the wire was observable and if the hanger had been in proper condition it would not have permitted the wire to sag. Such evidence was sufficient to make the question of the coal company's negligence one of fact to be submitted to and determined by the jury.

West Kentucky Coal Co. v. Key (Kentucky), 198 Southwestern, 724, p. 726.

DUTY TO WARN OR INSTRUCT.

HAZARDOUS UNDERTAKING—COMPETENCY OF EMPLOYEE—WARNING EXCUSED.

Where a person of full age who for more than two years had been employed in and about various mines, had seen others at work drilling and blasting rock with powder and who had worked as a miner sufficiently long for his own experience to have taught him the dangers attending the use of powder for blasting, seeks employment as a miner from a mine operator, the mine operator has the right to assume that such person has sufficient knowledge and skill to properly discharge the duties of the employment he seeks; and if he was not skilled in the use of powder in blasting he should, when directed to do such work, have informed the operator of his lack of experience and want of skill in the use of such dangerous agency.

Olsen v. Triangle Min. Co. (Utah), 167 Pacific, 813, p. 815.

ASSURANCE OF SAFETY.**RIGHT OF MINER TO RELY UPON.**

A miner was employed to remove from a room slate that had fallen. It was no part of his duty to inspect the roof, and he was under no duty to look out for the safety of the place where he was working. It was the duty of the mine foreman to inspect the roof at least once each day so as to protect the miner and others working thereunder from danger. At the time the miner was directed to go to this place to work he objected, because he thought the place was dangerous. The mine foreman informed him that the slate had fallen out, that the roof had become arched and the room was then a safe place in which to work. The foreman at that time went to the place with the miner, inspected it, and assured him of its safety. The place was not obviously dangerous, and the roof did not appear unsafe at the time the miner began working under it. Under such circumstances the miner had the right to rely upon the assurances of the mine foreman as to the safety of the place in which he was directed to work.

Consolidated Coal Co. v. Spencer (Kentucky), 197 Southwestern, 1069.

Where a miner is employed and where it is his duty to make his working place safe, and this he did by pulling down the loose slate or by propping the slate, the mere assurance of safety will not constitute a ground of recovery or impose any liability upon the mine operator.

Lytle v. Rex Coal Co. (Kentucky), 197 Southwestern, 1070, p. 1071.

Where a mine operator especially delegated to an employee or to one acting as his vice principal the duty of making an inspection of the quarry operations as they proceed, an employee working in the quarry may rely upon the assurances of safety made by such vice principal and proceed with his work, and the quarry operator is liable for injuries received by the employee while so working. The rule applies with particular force where the employer or the vice principal is a man of large experience and the employee has had but limited experience in the particular work.

Gray Eagle Marble Co. v. Perry (Tennessee), 197 Southwestern, 674.

ASSURANCE OF SAFE PLACE—DIRECTIONS TO WORK.

A conversation between a mine foreman and a miner some 60 feet distant from the miner's working place, where in answer to an inquiry by the mine foreman as to why the miner was not loading, the miner informed the foreman that he had just shot and there was too much smoke. The foreman said to the miner in substance: "I will go and shut the trapdoor on the main entry and you go on back to work." The purpose of closing the trapdoor was to remove the smoke, of

which the miner complained. The foreman did not direct the miner to go back to his work and in the meantime he would close the door; and the conversation can not be construed to be meant as a command to return to work until the trapdoor was closed, and in no sense was it an assurance of safety or that the miner's working place was safe, as the miner himself knew that the foreman had not been nearer than the 60 feet of his working place.

Gregg v. Stonega Coke & Coal Co. (Kentucky), 198 Southwestern, 5.

MINER MAY ASSUME PLACE IS SAFE.

A miner has a right to assume, in the absence of apparent defects, that the place in which he is ordered to work by a shift boss is safe, and he is not bound to inspect it for the purpose of discovering latent defects, and where a miner is directed to work in a certain place he has a right to act on the presumption that the mine operator has made his place of work reasonably safe.

Cnkovch v. Success Min. Co. (Idaho), 166 Pacific, 567, p. 570.

ASSUMPTION THAT OPERATOR HAS PERFORMED DUTY.

It is the duty of a mine operator to furnish his miners a reasonably safe place in which to perform the work assigned to him, and the miner has the right to assume that the operator has performed this duty. If an injury results from the failure to perform this duty the operator is liable, unless a reasonably prudent and intelligent man under like circumstances would have been able to discern the defects and failed to do so, thereby contributing to his injury. It is the duty of a mine operator to have the rooms in the mines inspected and see if they are in a reasonably safe condition for the miners to work.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 562.

A mine operator can not escape liability for his failure to perform a statutory duty on the ground that he did not know that the place was dangerous or that loose rock was likely to fall. A mine operator can not say that because an injured miner was experienced he was guilty of contributory negligence where no duty was imposed upon the miner to keep careful watch to see that loose rock did not fall upon him. Where the statute imposes this duty upon the operator, a miner has the right to rely upon the performance by the mine operator of the statutory duty to inspect and keep the roof of the entries propped to prevent stone from falling. The assumption by the mine operator that he was only bound by ordinary diligence to furnish a safe place for his miner to work would deprive the statute of all its force. A court can not assume that the legislature intended merely to declare that to be the duty of a mine operator which the common law already imposed upon him.

McAlester-Edwards Coal Co. v. Hoffar (Oklahoma), 166 Pacific, 740, p. 742.

RULES AND REGULATIONS.**FAILURE TO PROMULGATE RULES—EFFECT ON NEGLIGENCE.**

In the absence of evidence showing that rules would be useful or feasible under the circumstances, an employer can not be found negligent in not having promulgated a set of rules. Where the very nature of the employment makes it dangerous and the dangers incident thereto and growing out of it are of common knowledge and are fully known to and understood by the employee, and where the safety of others can not be imperiled in any way by any act or omission of one employee in the performance of his duties and his safety depends wholly upon the degree of skill, care, and caution used by the employee himself and not upon that of his fellow employees, the employer can not be held liable on account of his failure to furnish his employees with rules for the government of the employment, and under such circumstances the absence of rules is not proof of negligence on the part of the employer.

Olsen v. Triangle Min. Co. (Utah), 167 Pacific, 813, p. 816.

PROOF OF EXISTENCE OF RULES.

In an action by a coal miner for damages for injuries received while assisting in the operation of a coal-cutting machine, where the proof of the existence of a certain rule requiring the machine operator and his helper to carefully examine their working place for a dangerous roof and to see as the work progressed that the roof was not becoming unsafe, it is the duty of the court to instruct the jury as to the existence of the rule and the effect of disobedience of the rule. But where, in addition to the proof of such a rule, there was some proof tending to show that an old and different rule was in force, it was proper for the court to instruct the jury as to the effect of the violation of the rule, but the fact of the existence of the rule was to be determined by the jury under the contradictory evidence.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 563.

DANGEROUS EMPLOYMENT—RULES NECESSARY.

There are certain kinds of employment where, on account of their nature, it becomes necessary and it is the duty of an employer to promulgate and publish rules and regulations for the guidance and governance and safety of the employees. This is especially true where a large number of persons are at work and the danger or safety of the employment depends largely upon all the employees performing their duties promptly at stated times and in a given manner.

Olsen v. Triangle Min. Co. (Utah), 167 Pacific, 813, p. 816.

HAZARDOUS BUSINESS—RULES AND REGULATIONS.

A mine operator or other employer is not justified in conducting a hazardous and complicated business without some system of rules and regulations calculated to lessen the risks his employees will necessarily incur while engaged in their employment. But this principle has no application where a single employee was engaged in the performance of all the duties attending the work at the time of his injury, and where he was sufficiently mature in years and in experience to understand and appreciate the duties attending the work and where it is apparent that a system of rules would not in the slightest degree avoid the accident and resulting injuries.

Olsen v. Triangle Min. Co. (Utah), 167 Pacific, 813, p. 815.

DELEGATION OF DUTY.**NONDELEGABLE DUTY.**

The duty of an employer to furnish a reasonably safe place for his employees to work in and reasonably safe tools and appliances for the employees to work with is a nondelegable duty.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021, p. 1022.

MINER'S WORKING PLACE—SAFE PLACE.**APPLICATION OF SAFE-PLACE DOCTRINE.**

The safe-place doctrine and the duty of a mine operator to furnish a miner a sufficient working place applies where the operator selects the place and directs the miner to work at and in such place, and where the miner himself in no way creates the place or changes it by the work he is engaged in doing pursuant to the directions given, and where the dangers are from outside sources and over which the miner has no control and which are not within his view.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

FAILURE OF OPERATOR TO EXERCISE CARE.

A miner engaged in mining coal was by the mine foreman taken to another part of the mine and directed to repair the tracks in a haulageway. The tracks had spread, thereby permitting cars to become derailed, and while the miner was engaged in repairing the tracks another miner pushed a loaded car down the track that became derailed, and the miner who had been directed to repair the track, while engaged in such work and in assisting to place the loaded car back on the tracks, was injured by a collision from a trip of empty cars being pushed into and through the haulageway. The mine foreman knew of the situation, the condition of the track, and the duty of the miner to make the repairs. He knew as he walked out of the haulageway that a motor was pushing or would push

empty cars into such haulageway; he knew also that the place where the miner worked was not lighted, and that there were no lights on the empty cars pushed into such particular haulageway. Under these circumstances the mine operator was justly found guilty of actionable negligence in not exercising due care to provide the miner a safe working place.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

MINER MAKING WORKING PLACE.

The rule requiring a mine operator to furnish a miner a safe place to work does not apply where the miner himself is charged with the duty of taking down the slate for his own protection, and where the perils to which he is subjected were of his own creation.

Gregg v. Stonega Coke & Coal Co. (Kentucky), 198 Southwestern, 5.

MINER INJURED WHILE MAKING PLACE SAFE—LIABILITY OF OPERATOR.

A miner injured while taking down draw slate from his working place can not recover damages from the operator for injuries where it was the miner's duty and the miner had assumed the duty of propping and taking down the slate and himself making his working place safe. The safe-place doctrine has no application under such circumstances.

Lyttle v. Rex Coal Co. (Kentucky), 197 Southwestern, 1070, p. 1071.

Gregg v. Stonega Coke & Coal Co. (Kentucky), 198 Southwestern, 5.

RELATIVE DUTY OF OPERATOR AND MINERS.

As the work of mining progresses in a mine under some circumstances there comes a time when it is a question as to what is the working place of the miner, and whether it has passed out of his control and the duty devolved upon the operator to look after the roof. It becomes a question where the miner's duty ceases and the employer's duty begins and especially where the limits of the miner's working place are not defined or fixed by statute. If as a fact to be established by the proof, the miner in the progress of his work and his working place have passed beyond the point in controversy and that part of his room has become in fact a roadway for taking out the coal, then the duty would devolve upon the operator to secure the roof. But these are questions of fact to be submitted to and determined by a jury.

Mitchell v. Phillips Min. Co. (Iowa), 165 Northwestern, 108, p. 112.

DUTY OF INSPECTION.

A miner was injured by a fall of slate from the roof at a place where he was directed by the mine foreman to load out slate that had fallen and with the assurance of the foreman that the place was safe. Where it was the duty of the foreman and not of the miner to inspect

the roof, proof that, when loading out coal, it was the duty of the miner to inspect and make safe the roof under which he was working is not available to a mine operator in an action by the injured miner for damages, where the mine foreman admitted that the kind of work the miner was doing at the time of the accident imposed upon the operator and not upon the miner, the duty of inspecting and maintaining in a safe condition the place where he was working.

Consolidated Coal Co. v. Spencer (Kentucky), 197 Southwestern, 1069, p. 1070.

BLASTING—DUTY OF MINER AS TO SHOTS.

A miner whose duty it is to prepare and fire the blasting charges in his working place must observe and take the precaution for himself that miners generally do while engaged in such work. The procedure of a miner always counting his shots to determine an explosion from each of his charges of powder is thoroughly well known, recognized, and universally followed by miners. No miner can be entirely safe unless he thoroughly examines each of the places where he puts any charge of powder and there is no way in which the danger of injury can be avoided except a careful observation by the miner himself of the places where he has put the explosive in the holes.

Olsen v. Triangle Min. Co. (Utah), 167 Pacific, 813, p. 816.

DUTY OF MINER TO PROP.

The duty is upon a miner to prop the roof of his working place and a coal mining company can not be charged with negligence in failing to prop the roof of a miner's working place.

Hyden v. Stearns Lumber & Coal Co. (Kentucky), 198 Southwestern, 775.

KNOWLEDGE OF DEFECTS—INSUFFICIENT PLEADING.

A plea or answer to a complaint by a miner for damages for injuries caused by a fall of rock from the roof of the mine where the plaintiff was working is insufficient where it avers that at the time the plaintiff sustained the injuries he was engaged in mining ore as an employee of the defendant operator, and while so engaged a piece of rock became loose and was likely to fall and such fact was known to the plaintiff. It also averred that the duty of the plaintiff was either to pull down the rock or to notify the mine boss that the rock was loose and not to go under it until a timber had been set by the proper employee. The plea charges the complainant with the knowledge of the defect but not with a knowledge of the danger and charges the duty to the plaintiff in the alternative either to remove the rock or to notify the mine boss. There is no averment that the complainant did not discharge the duty of notifying the mine boss

and only inferentially charges that he did not pull down the rock. The averments of the plea admit the injury could have been the proximate cause of the negligent failure of the operator's agent after such notice to promptly remedy the defect within a reasonable time thereafter. The plea does not charge the complainant with a knowledge of the danger or that it was open or obvious.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 77.

MINER'S SCOPE OF EMPLOYMENT.

SCOPE OF EMPLOYMENT—PLEADING.

In an action by a miner for damages for injuries received while working in a mine it is sufficient to show that the injuries were received within the scope of the miner's employment where he averred in his complaint that at the time he received the alleged injuries he was acting within the line and scope of his employment with the mine operator.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 76.

NEGLIGENCE OF FOREMAN, OFFICER, OR VICE PRINCIPAL.

WHAT CONSTITUTES—EMPLOYEE IN CHARGE.

An employee in charge of an employer's business or any department thereof, whose duties are exclusively supervisory and who is in the direction and control of the work of all subordinate employees engaged therein, whose duty it is to obey him, is a vice principal, although he may be subject to general orders or superintending control of a general manager.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021, p. 1022.

NEGLIGENCE OF VICE PRINCIPAL.

There are certain absolute or nondelegable duties which the law casts upon an employer for the protection of his employees; and an employee, of whatever rank, to whom the master delegates the performance of such duties is his vice principal and not a fellow servant. In all such cases the employer is liable to a miner for injuries due to the negligence of such vice principal in the performance of such duties.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021, p. 1022.

EVIDENCE—DECLARATIONS OF VICE PRINCIPAL—PROOF.

The declarations of a superintendent of an oil company as a vice principal made within the scope of his authority and while transacting the business of his principal, may properly be admitted in evidence.

Wolverine Oil Co. v. Kingsbury (Oklahoma), 168 Pacific, 1021, p. 1022.

HOISTING ENGINEER.

A hoisting engineer employed by a mine operator to run and operate the engine and machinery that raise and lower the cage by which miners enter the mine, is a vice principal of the corporation and was employed to do work which could only be done by the company. A mining company is responsible for the manner in which the hoisting engineer does his work and can not even if desired, evade the responsibility or shift the burden to the shoulders of another. The negligence of the hoisting engineer is under such circumstances the negligence of the mining company and a complaint in an action by a miner for injuries caused by the negligence of the engineer may properly charge both the engineer and the mining company with negligence. The failure of proof to show negligence in the employment of the engineer can not in any way affect the allegations charging both the engineer and the mining company with negligence in operating the cage, and that was the proximate cause of the injury complained of.

Farnon v. Silver King Coalition Mines Co., (Utah), 167 Pacific, 677.

NEGLIGENCE OF FELLOW SERVANT.**WHO ARE FELLOW SERVANTS—BOTTOM BOSS.**

A person known as a "bottom boss" had the direction of the bottom men and in the absence of the mine manager, directed the motor drivers where to stop or place the cars when they came to the bottom and also gave directions for the distribution of the empties. He was not authorized to give motor drivers any orders or instructions as to what they should do or as to how they should run their motors after they left the bottom or main entry or as to how they should drive over the crossovers or runarounds in going for the empties. He received special orders each morning and noon as to what he should direct or tell the men to do and it was his duty to carry out these orders exactly as given; he only controlled the movements of the loaded and empty cars when they came to the bottom to be hoisted. Under such a state of facts, the bottom boss is not a fellow servant of a motor driver and does not stand as to a motor driver in the position of vice principal and is entitled to recover for injuries caused by being run over by a motor in a cross passage by reason of the negligence of the mine operator.

Daly v. New Staunton Coal Co. (Illinois), 117 Northeastern, 413, p. 415.

WHO ARE FELLOW SERVANTS—RULE IN KENTUCKY.

The courts of Kentucky are committed to the doctrine of the "association theory" or in other words, an employer will not be excused for negligence resulting in injury to one employee which is inflicted by another employee, unless such employees are so engaged

and situated so that each by carefulness and attention in the performance of his duties may protect himself from injury caused by the negligence of the employee with whom he is working. This rule has been applied to two drivers in a mine, each driving mules attached to different trips of cars; to motormen operating different cars in the same mine; to operators of separate cars in a rock quarry hauling rock to a crusher, and to employees, one operating a trip of empty cars and another on a different track operating a trip of loaded cars. In each of these instances the employees have been held not to be fellow servants.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075.

MINERS OPERATING DIFFERENT TRIPS OF CARS.

It was the duty of one miner to receive loaded cars from a mine at the foot of an incline, and conduct them across a trestle to the tippie. It was the duty of another employee, a hostler, to take the empty cars up the incline, release the cable, and take the cars into the mine. The hostler while taking a trip of empties up the incline negligently and prematurely detached the cable before the trip reached the top, thereby causing the trip of empty cars to run down the incline and against and upon the other miner, who was taking the loaded cars across the trestle. The two employees were operating separate cuts of cars, were in no way associated with each other, and neither was in position to see or know what the other was doing or how he was performing his duty. Under such circumstances such employees can not be held to be fellow servants under the rule adhered to by the courts of Kentucky.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075.

HOISTING ENGINEER NOT FELLOW SERVANT.

A hoisting engineer employed by a mine operator to run and manage the engine that raises and lowers a cage from one level to another, is not a fellow servant with a miner injured by the negligent dropping of the cage.

Farnon v. Silver King Coalition Mines Co. (Utah), 167 Pacific, 677.

CONTRIBUTORY NEGLIGENCE OF MINER.

PLEADING CONTRIBUTORY NEGLIGENCE—SUFFICIENCY OF PLEA.

A plea of contributory negligence is not sufficient where it merely states a conclusion of law; but it must aver the facts constituting the negligence and the facts so averred must be such that a conclusion of negligence follows therefrom as a matter of law.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 77.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075, p. 1077.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47, p. 48.

A plea of contributory negligence is not sufficient where it avers in substance that there was a safe way to perform the work and labor which the deceased miner was doing at the time a dipper fell upon and injured him and that the intestate failed and refused to perform the work in the safe way and placed himself within a few feet of the car being at the time loaded, where he knew derricks might fall on him or the dipper might strike him, and remained in said place while the dipper was swung over the car and fell and thereby caused his death.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47.

A plea of contributory negligence to be sufficient must go beyond averring negligence as a conclusion and must aver a state of facts to which the law attaches that conclusion.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47, p. 48.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 77.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075, p. 1077.

In an action for the death of a miner caused by the negligence of a mine operator, the mine operator filed an attempted plea of contributory negligence as follows: "The defendant says that the deceased contributed to his own injury from which he died." This is not a good plea of contributory negligence as it does not allege that the deceased was negligent, and that his negligence contributed to his injury, but for which the injury would not have occurred, all of which allegations are necessary to such a pleading.

Harris v. Rex Coal Co. (Kentucky), 197 Southwestern, 1075, p. 1077.

Sloss-Sheffield Steel & Iron Co. v. Harrison (Alabama), 76 Southern, 47.

Clinton Mining Co. v. Bradford (Alabama), 76 Southern, 74, p. 77.

PLEADING AND INSTRUCTIONS.

When specific facts are alleged as constituting contributory negligence on the part of a miner suing for damages for injuries the instructions of the court to the jury on the trial of the case should be confined to the specific facts stated; but where in such case the mine operator pleads contributory negligence in general terms and introduces evidence under such a plea, he is entitled to a special instruction on such negligence in which the facts are grouped and the law applied thereto; and a refusal on the part of the court to give such instructions is error.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 563.

QUESTION OF FACT.

Whether or not a track repairer who had stopped his work and was injured by a collision of empty cars while he was engaged in assisting to replace a loaded car on the tracks, was guilty of contributory negligence in failing to look for or see or get out of the way of the empty

cars was a question to be determined by the jury in an action by him for damages for the injuries sustained.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

QUESTION OF LAW OR FACT.

The statute of Virginia enacts under penalty that no person shall travel on foot to and from his work upon any slope, engine plane, or motor road where another good road is provided. But a court can not say as a matter of law in case a miner while traveling on foot to his work on a motor road was guilty of contributory negligence where there was evidence tending to show that the roof of the manway was not safe and there was evidence tending to prove a custom for miners and employees to go into the mine on the motor road and take the cars inside of the mine. Under such circumstances it is a question of fact whether the method adopted by the miner was authorized and sanctioned by the mine operator, and if it was the miner was not guilty of contributory negligence.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 373.

QUESTION OF FACT—FAILURE TO INSPECT WORKING PLACE.

A helper in operating an electric coal-cutting machine was injured by a fall of slate from the roof of the mine. A rule of the mine operator imposed upon the operator of a coal-cutting machine and of his helper the duty of careful examination of the roof and to satisfy themselves that it was safe. The room in which the accident occurred had been cleared and propped the usual distance by the coal loaders, a part of whose duties were to secure the room and have it in readiness for the machine operator and his helper. The proof showed that it was not in this particular part of the room that the helper was injured by the falling slate. The proof also showed that the mine foreman knew of the bad condition of the roof and that the machine helper did not know that fact, although he had picked a hole or place in the roof for the purpose of setting a jack, but he had not been in the room before he began to work there and knew nothing of its condition. Under the established facts a court can not say as a matter of law that the helper was guilty of contributory negligence, or that he was negligent in not making a proper examination or inspection of the roof and that this negligence contributed to his injury.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 562.

BURDEN OF PROOF.

In an action for damages for the death of a miner due to the alleged negligence of the mine operator in not properly adjusting a live electric wire and by reason of which the driver was killed, the

burden of proving contributory negligence rests upon the defendant, the mine operator, unless the fact of contributory negligence appears from the plaintiff's own evidence.

Virginia Iron, Coal & Coke Co. v. Prophet (Virginia), 93 Southeastern, 590, p. 591.

NEGLECT OF DUTY.

Contributory negligence is a delict or neglect of duty by an employee and he can not recover for a delict of his employer even in the violation of a statute, if his own delict has contributed to his injury as a proximate cause.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 372.

KNOWLEDGE OF DANGER—OPERATOR'S WANTON NEGLIGENCE.

A recovery by a miner for damages for injuries caused by a fall of rock from the roof is not to be defeated because the miner knew of the dangerous condition of the roof and that a prop was needed and knew that props had not been furnished, and although, he continued after such time to make conditions more dangerous by the work he was doing, where the evidence shows that the mine operator had knowledge of the dangerous condition of the roof and notwithstanding said knowledge "grossly and wantonly and recklessly permitted said roof to remain in said defective condition and plaintiff was proximately injured from said gross and wanton negligence."

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, 76.

KNOWLEDGE OF DANGER—MAKING DANGEROUS PLACE SAFE.

A miner was employed to assist in the work preliminary to installing a telephone line, and his duty was to assist in cutting a groove for the wire along the side of an entry and the taking down of all loose coal above the groove that by falling or sinking might close the groove and break the wire. In the progress of the work he and a miner assisting him reached a place in the entry where the coal was drummy. The miner assisting warned the other not to dig there as the overhanging brow of loose coal if dug under would fall; the other believing he could knock out enough coal to clear the line proceeded, and while so engaged the coal fell, producing injuries from which he died. Under such circumstances there can be no recovery for the death of the miner for three reasons: First, no negligence can be imputed to the mining company in relation to the injury; second, the miner himself was clearly negligent and his negligence was the sole cause of the accident; third, he was employed to remove the drummy coal so that the telephone line might not be interfered with or broken by any subsequent fall.

Dodd v. Pocahontas Consol. Collieries Co., 244 Federal, 151, p. 153.

KNOWLEDGE OF DANGER—VIOLATION OF RULES.

Empty cars drawn by an electric motor supplied by an overhead feed wire were used by a mine operator to haul the miners at the end of their shift to the foot of the mine slope to be taken out of the mine. The miners at the end of the shift collected at a certain place, the cars brought to and stopped near by, and the current turned off of the wire above the empty cars before the miners were permitted to board them. The boarding of the cars before they were stopped and before the current was turned off was extremely dangerous and hazardous, and this fact was well known to all the miners. A miner who with knowledge of the dangers and who over the protest, commands, and warning of a foreman and safety-first man, attempted to get on the front car of the trip before the cars were stopped and before the current was turned off, and to avoid the probable inconvenience of waiting 10 or 15 minutes to be carried out of the mine after arriving at the slope, was, as a matter of law, guilty of contributory negligence and such negligence was the proximate cause of his death.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

OBVIOUS DANGER.

In order to charge an injured miner with contributory negligence and defeat his right of recovery, the dangers, and not the defects merely, must have been so obvious and threatening that a reasonably prudent man would have avoided them.

Cnkovch v. Success Min. Co. (Idaho), 166 Pacific, 567, p. 570.

DANGER NOT IMMINENT.

An action for the death of a miner killed by a fall of slate can not be defeated on the ground of contributory negligence from the fact that the miner went under parting slate without props, where it appeared that before going under the slate the deceased, in a proper manner examined and tested the slate in the presence of another miner and that in the judgment of this miner and presumably in the judgment of the deceased, it was safe to proceed under the slate and where there was some evidence tending to prove that the danger was neither obvious nor imminent.

Thacker v. Shelby Coal Min. Co. (Kentucky), 197 Southwestern, 633, p. 634.

RISK OF DANGER TO AVOID INCONVENIENCE.

When the question is one of mere convenience and not of actual danger, some moderate risk may be taken if there is no obvious danger. But a miner will be chargeable with contributory negligence if he takes the risk of an obvious and serious danger merely to avoid inconvenience or to save a few minutes time.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

MINER'S VIOLATION OF OPERATOR'S ORDER.

Under some circumstances a violation of an order of a mine operator by an employee might not amount to more than contributory negligence but a willful violation of a direct and positive order of a mine operator by a miner and by reason of which the miner lost his life, will be sufficient to defeat an action for damages for the death, although the mine operator violated the statute, but his violation of the statute was not the proximate cause of the miner's death.

Randall v. Crescent Coal Co. (Illinois), 117 Northeastern, 773, p. 777.

MINER STANDING ON MOTOR TRACK IN ENTRY.

Certain employees and miners while entering a mine on foot were warned of a trip of empty cars coming rapidly on the other track leading into the mine. There was a space sufficient for the miners to stand between the tracks in safety; but to avoid the empty cars a miner stepped back near to and upon the other track and while the empty cars were passing at a rapid rate and making a loud noise, a trip of loaded cars, without any light on the front of the car or any signal or warning of any kind, was being pushed by a motor out of the mine on the opposite track and struck and killed the miner. It was a violation of the statute of Virginia to push the trip of loaded cars out of the mine without a light on the front car; and to hold that without such warning it is contributory negligence per se for a miner to stand on a track in the narrow space of a coal mine because there is another sufficient place to stand would be to exact as a matter of law perfection of carefulness.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 373.

ASSUMPTION OF RISK.**RISKS ASSUMED.****ORIGIN OF ASSUMPTION OF RISK.**

Assumption of risk rises either out of the contract or status of employment as an incident to it, or out of the status of relation voluntarily assumed and continued by the employee toward the instrumentalities of the employer.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 372.

DOCTRINE OF ASSUMED RISK.

Assumption of the risk of a business inherently dangerous but conducted with due care is a doctrine evidently fair and just.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

RISKS INCIDENT TO SERVICE.

A coal miner assumes the risk of dangers which are ordinarily incident to the services or that are open and obvious which the law will infer are so known to him.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

RISKS KNOWN AND APPRECIATED.

A coal miner assumes the risk of dangers which are known to and appreciated by him.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 602.

DEFENSES—PLEADING.

Assumption of risk on the part of an employee or miner is an affirmative defense to be established by the mine operator. A mine operator who pleaded assumption of risk as a defense to an action by a miner injured by the failure of the operator to place a light on a trip of cars, can not successfully interpose such defense, where he must assert and prove, as one of the elements, his own violation of a penal statute. The rule is that no one can assert an affirmative claim of any kind where one of its essential elements is his own violation of a criminal statute.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 372.

OBVIOUS DANGER.

A skilled mechanic, a carpenter, a part of whose duties was to inspect and keep in repair a place in the mine tracks assumed the risk where the danger of attempting to replace a loaded car upon the tracks was obvious.

Mcmennimen v. Lehigh Valley Coal Co. (Pennsylvania), 101 Atlantic, 735, p. 736

KNOWLEDGE OF DANGEROUS ELECTRICAL APPLIANCES.

A coal mining company used an electric motor to haul the cars through the various entries and on which at quitting time the miners rode to the foot of the shaft or slope. The trolley wire or feed wire was at the top of the entry about 5 feet 7 inches above the track. When the cars were brought up for the miners to board, to be carried through the entry, they were stopped and the miners boarded the car on the side opposite the trolley wire. The miners employed were all familiar with the situation, the condition and danger of the trolley wire, and the necessity of boarding the car from the side opposite the feed wire. Under these circumstances the miners in boarding the car and in riding in and out of the mine assumed the risk of the danger from the live trolley wire and the electrical appliances.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

CHANGING CONDITIONS OF MINER'S WORKING PLACE.

The doctrine of assumption of risk applies to a miner's working place, where such working place is constantly changing by reason of the operations of the miner himself.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

MINER'S WORKING PLACE—KNOWLEDGE OF DANGER.

An experienced miner had fired two shots for the purpose of loosening the coal at his working place. He had gone to a breakthrough some 60 feet distant when the shots were fired, and waited for the smoke to clear away. The mine foreman who met him and learned of the shots and the smoke, informed the miner that he would go 1,000 feet distant and close a trapdoor so that the smoke would disappear; but without waiting for the trapdoor to be closed and the smoke to clear away, the miner returned immediately to his work. He had just loosened the coal by firing two shots, and he knew that the roof support had thus been removed, and that there was nothing to prevent the slate from falling. He admitted that the smoke was so thick that he could not see. Under these circumstances he must be held to have assumed the risk of the danger.

Gregg v. Stonega Coke & Coal Co. (Kentucky), 198 Southwestern, 5.

WARNING—OPERATOR'S FAILURE TO COMPEL OBEDIENCE—LIABILITY.

It is sufficient where a coal-mine operator promulgates and attempts in reasonable ways to enforce a rule governing the conduct of miners in a particular instance. A coal-mine operator used an electric motor and cars for conveying the miners from their working places at quitting times through the entries to the foot of the shaft or slope. The rule was that the miners should not board the cars until brought to a standstill at the place where the miners collected and until the current was turned off of the part of the feed wire that extended over the empty cars, and then the miners were to board the cars from the side opposite the feed wire and in no other manner. It required two trips to take an entire shift up the main slope, and the miners who first boarded the cars had the advantage of taking the first trip up the slope. To gain this advantage the miners sometimes boarded the cars from the ends and sometimes before the cars were stopped and the current turned off. The operator kept a foreman, known as a "safety-first," man at the place and at the times where the miners collected for the purpose of warning them and preventing them from boarding the cars until stopped and the current turned off. At the time one of the miners was killed by coming in contact with the live wire and for which the operator was sued, the safety-first man did all that was reasonable and all that was within his power, except the use of physical force to prevent the miners, including the deceased, from boarding

the cars before they were stopped and the current turned off. The operator could not be expected or required to do more in an honest endeavor to enforce the rule and can not be held liable for the death of the miner where the deceased, together with others by their force of numbers, pushed by and disregarded the warning and protest and commands of the safety-first man. The operator could not be expected, and certainly was not required, to use physical force to prevent the deceased and the other miners from boarding the cars prematurely.

Whalen v. Union Pacific Coal Co. (Utah), 168 Pacific, 99, p. 104.

DANGEROUS CONDITION OF ROOF.

A rule in a mine where an electric coal-cutting machine was used required the operator of the machine and his helper to inspect and to keep propped and in safe condition the roof of the part of the room in front of the coal-cutting machine. Under such a rule neither the machine operator nor his helper assumes the danger of any part of the room which they are not required to inspect or make safe as they proceed in the cutting of the coal.

Consolidation Coal Co. v. Bailey (Kentucky), 198 Southwestern, 561, p. 562.

MINER USING DEFECTIVE COAL-CUTTING MACHINE.

A miner was furnished a coal-cutting machine that was defective and badly out of repair. He was an experienced miner and had worked as a machine operator and had operated the particular machine, or one like it, for some three years, during the last three months of which time and immediately preceding the injury complained of the machine as admitted by the miner was out of repair "in every way in the world. Every speck of it was out of repair;" and that during the three months he had taken it to the shop as often as 25 or 30 times, but the condition of the machine remained the same during the entire three months. The miner from the facts disclosed, was thoroughly aware of the danger and of the possibility of just such an accident as did in fact happen to him and that continuing in the service with the machine in such condition for such a length of time and without any assurance as to his safety in the use of the machine and without any promise on the part of the mine operator to repair or improve the machine, he assumed the risk incident to its use.

Stonega Coke & Coal Co. v. Bush (Kentucky), 197 Southwestern, 389, p. 390.

RISKS NOT ASSUMED.

EMPLOYEE CAN NOT WAIVE OR CONTRACT AGAINST VIOLATION OF STATUTE.

The Legislature of Virginia assumed that men will work in the mines of the State without the protection of lights on the cars as required by the statute; otherwise the statute would not have been

necessary. The precautions obviously necessary to safety the legislature placed out of the domain of waiver by the employee, or of contract, either express or implied, between the parties, and requires these precautions as a matter of public policy and under the sanction of a penalty inflicted for failure to provide them.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

VIOLATION OF STATUTE BY OPERATOR.

An employee in a coal mine does not assume the risk of a known violation by the employer of a penal statute requiring a light on the front and on the rear of trips of cars in coal mines, provisions deemed by the legislature necessary for the safety of employees in mines.

Pocahontas Consol. Collieries Co. v. Johnson, 244 Federal, 368, p. 371.

MINER'S KNOWLEDGE OF DANGER—OPERATOR'S WANTON NEGLIGENCE.

A miner is not to be charged with the assumption of risk and his action for damages for injuries caused by a fall of rock from the roof defeated, although he knew of the dangerous condition of the roof, and that a prop was needed and that props had not been furnished, and continued to make conditions more dangerous by the work he was doing, where the evidence shows that the mine operator had knowledge of the dangerous condition of the roof and that he grossly, wantonly, and recklessly permitted the roof to remain in its defective condition and the plaintiff was proximately injured by reason of said gross and wanton negligence.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 76.

MINER WORKING UNDER SHIFT BOSS—ASSURANCE OF SAFETY.

It is the duty of a miner to do such work and in such manner as the operator's shift boss may direct; and where a miner is directed by a shift boss to bar down and make safe the place where he was working it is his duty to follow such directions and it is not a part of his duty to inspect the part of the stope above him that could not be seen by the aid of his miner's lamp and that could not be examined by any means provided. Under such circumstances the miner does not assume the danger from loose rock in the roof of the stope, and it is proper in an action by the miner for injuries received from a fall from the roof for him to testify that the shift boss told him that the ground or condition above him was all right.

Cnkovch v. Success Min. Co. (Idaho), 166 Pacific, 567, p. 570.

OPERATIONS OF EMPLOYER NOT IN VIEW OF EMPLOYEE.

A miner in his working place in a mine and while in the place assigned to him in which to work does not assume the risk of dangers from other operations of the employer that are not within his view and which are obstructed from his sight and of which he has no warning.

Clinchfield Coal Corp. v. Ray (Virginia), 93 Southeastern, 601, p. 604.

DANGEROUS ROOF—MINER REMOVING FALLEN SLATE

A miner was employed simply to remove from a room slate that had fallen and it was the duty of the mine operator and not of the miner to make and maintain the roof at the place of the accident in a reasonably safe condition for the work the miner was then doing. It was the duty of the mine foreman to inspect the roof at least once each day so as to protect from injury the miner and others working thereunder; but on the particular occasion the foreman did not inspect the roof from the time he directed the miner to go to work there until after the accident. Under such circumstances the miner was under no duty to look out for the safety of the place where he was working and he did not assume the risks incident to such work.

Consolidated Coal Co. v. Spencer (Kentucky), 197 Southwestern, 1069, p. 1070.

RIGHT TO SURFACE REPORT.**MINING AND REMOVING PILLARS—RIGHT TO INJUNCTION.**

A surface owner is not entitled to an injunction to prevent a coal mine operator from mining out pillars where the subsidence of the surface was complete and the legal injury occurred more than three years prior to the filing of the complainant's bill. The fact that the mine operator intends to mine the lower veins of coal will not entitle the surface owner to an injunction where no injury to the surface is apprehended from that source.

Drake v. Berry (Pennsylvania), 102 Atlantic, 315, p. 317.

NUISANCE.**SMELTER OPERATIONS—INJURIES FROM POISONOUS GASES.**

A farmer brought an action against a smelting company for damages for injuries to crops, live stock, and for the death of certain animals. The injuries were alleged to have been caused by the operation of the smelter whereby smoke, fumes, and poisonous gases arising from the smelting of copper, iron, zinc, silver, arsenic, and antimony and other minerals were discharged into the air and carried over and upon the plaintiff's lands. The evidence showed the death of certain horses and cows, and the symptoms during the progress of the sickness and disease resulting in death were described by the witnesses, but the witnesses could only conjecture that the sickness and death of the animals were caused by the smelter fumes and gases. The testimony also showed that during the same period of time there was prevalent in the vicinity a disease designated as infectious pneumonia and the disease had many symptoms similar to those of the complainant's animals. The testimony also showed that an infallible test can be made to determine whether or not an animal died from mineral poisoning and that such test was made on some of the animals that died and

no mineral poisoning was discovered. The evidence was not sufficient to establish that the animals died from the smoke, fumes, and poisonous gases resulting from the smelting operations.

Sagers v. International Smelting Co. (Utah), 168 Pacific, 105, p. 109.

OVERFLOW OF ARTESIAN WELL.

The continued overflow of an artesian well and permitting the waters to run to waste in large quantities result in the water-logging of land and destroy its productiveness. In view of these facts and of the further fact that the water in artesian wells comes from the same basin and the continued overflow of a well is necessarily a waste of water derived from the common source of supply and diminishes the water supply available for legitimate uses and works an injury and a detriment to the general public, the legislature has the power to declare such continuous flow and waste of water to be a public nuisance and to make regulations preventing or abating the same.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 728.

MINING LEASES.

LEASES GENERALLY—CONSTRUCTION.

CONSTRUCTION AND TERMINATION.

The owner of oil lands executed a mortgage thereon to secure certain indebtedness and subsequently executed a lease for the development of the land for oil. The foreclosure of the mortgage and a sale on the decree of foreclosure put an end to the leasehold interest.

Mercantile Trust Co. v. Sunset Road Oil Co. (California), 168 Pacific, 1037.

CONSTRUCTION—FORFEITURE—ACCEPTANCE OF RENT.

The acceptance of rent after covenants broken may estop a landlord from claiming forfeiture of the lease or reclaiming possession.

East Sioux Falls Quarry Co. v. Wisconsin Granite Co. (South Dakota), 164 Northwestern, 77.

CONSTRUCTION—ROYALTIES AS RENTALS.

A lease of a mine by which the owner or lessor grants to the lessee the privilege of mining and operating the same in consideration of the payment of a certain stipulated royalty on the ore taken out creates the relation of landlord and tenant and when that relation is created whatever is paid for the occupation and use of the premises, whether it be in money or kind, is equally in substance rent, and under such circumstances the royalties received are rentals and subject to taxation as such.

Phister Land Co. v. City of Milwaukee (Wisconsin), 165 Northwestern, 23, p. 25.
Von Baumbach v. Sargent Land Co., 242 U. S., 503.

HUSBAND AND WIFE—RIGHT TO ROYALTY.

A husband held the legal title to an one-fourth interest in a mining claim in trust for his wife who was the equitable owner thereof. The owner of the three-fourths interest leased such interest to the husband on condition that the husband was to operate the entire claim and pay the three-fourths lessor 25 per cent of the total output. Subsequently and before mining operations began the husband on a consideration conveyed the one-fourth interest to his wife and at the same time executed a sublease to a third person by which such third person was to pay him 5 per cent of the gross output in addition to the 25 per cent to be paid to the owner of the three-fourths interest, to which sublease the wife consented. The wife as

against the claims of the trustee of the bankrupt husband is entitled to the 5 per cent of the proceeds of the sublease, as the conveyance by the husband to the wife carried with it in legal effect the sublease executed by the husband.

Patterson v. Stroecker, 245 Federal, 732, p. 734.

PAROL AGREEMENT TO PURCHASE LEASE—STATUTE OF FRAUDS.

The complainant was negotiating with the owner of mineral lands for a lease of such lands for a period of 10 years. Pending the negotiations and before the execution of the lease, he entered into a contract with the defendants by which he was to sell and the defendants were to purchase the lease at the agreed price of \$5,000. The defendant at the time this agreement was entered into was carrying on mining operations on other lands of the landowner adjoining the lands proposed to be leased, and pursuant to such oral agreement the defendant began mining operations on the lands proposed to be leased to the complainant and under the verbal arrangement to purchase such lease and mined and removed more than \$30,000 worth of ore. The complainant instituted his action to recover of the defendant the \$5,000 agreed to be paid for the lease. A recovery was denied on the ground that the parol contract for the sale of the lease was within the statute of frauds. Thereupon the complainant instituted an action against the defendant to recover damages for use and occupation of the premises. As the parol contract for the purchase of the lease was void under the statute of frauds it could not create the relation of landlord and tenant and could not furnish a foundation for an action for use and occupation on the implied promise to pay and as the relation of landlord and tenant did not and could not exist by reason of such parol agreement, the complainant could not recover on the theory of a liability for use and occupation.

Wilson v. McInturff (Missouri Appeal), 198 Southwestern, 421.

See *Aylor v. McInturff*, 184 Missouri Appeal, 691, 171 Southwestern, 606.

LEASE OF INDIAN LANDS—APPROVAL BY COURT.

A mining lease of Indian lands was required by the order of the court to be submitted to and approved by the Secretary of the Interior. The fact that the court ordering the lease approved it does not annul the order requiring it to be approved by the Secretary where the terms of the lease itself and every condition of the lease make it manifest that it was drawn with reference to the power of the Secretary to approve or disapprove it and that its execution was subject to all the conditions, limitations, and restrictions resulting from such situation.

Wellsville Oil Co., v. Miller, 243 U. S., 6, p. 13.

COAL LEASES.

CONSTRUCTION—SEPARATE PROVISIONS CONSTRUED TOGETHER.

A coal-mining lease provided that if the lessee should cease operations for a period of three months it should work a forfeiture of the lease unless the delay was unavoidable. Another section of the lease provided that any failure on the part of the lessee to perform the conditions and covenants of the lease to be by him performed, that should continue for a period of 30 days, shall be deemed, at the option of the lessor, ipso facto, to work a forfeiture of the lease. This second provision does not give the lessee an additional 30 days before the forfeiture provided for in the first clause should become effective. The latter provision was a general forfeiture clause, while the former was a specific provision covering a particular situation not embraced within the terms of the general forfeiture clause. The lease must be interpreted as a whole and in such way as to give effect to all of its provisions, and the failure for three months to operate the mines could not be extended 30 days by the later provision.

Matoaka Coal Corp. v. Clinch Valley Min. Co. (Virginia), 93 Southeastern, 799, p. 803.

LEASE CONSTRUED IN CONNECTION WITH WILL.

A mining company was mining and operating certain tracts of land under a lease executed by the trustee of an insane person who was the owner of an interest in the land and coal. The coal company also owned an interest in the land. The rights of the parties depended upon the will of the deceased ancestor of such insane person as well as the lease under which the coal company was operating. The trustee of the insane part owner sought by a bill in equity to have an accounting and to enjoin the further removal of coal by the coal company. A court could not grant the relief demanded where a copy of the will was not filed with or as a part of the plaintiff's bill, inasmuch as the court could not accept the plaintiff's construction of the will upon which he based his right to the relief demanded.

Wilmer v. Philadelphia-Reading Coal & Iron Co. (Maryland), 101 Atlantic, 538, p. 540.

CONSTRUCTION—MINER'S WEIGHT.

The term "miner's weight" used in a coal-mining lease as the basis for the price per ton to be paid for mining, is not a fixed, unvarying quantity of mine-run material, but is such quantity of material as operators and miners may, from time to time, agree as being necessary or sufficient to produce a ton of prepared coal. The term used in a coal-mining lease executed in 1863 was manifestly adopted by the lessor and lessee as meaning the ton-weight of material required to be mined as equivalent to a ton of prepared coal. The

term must be held to mean a miner's weight ton as fixed and agreed upon by the operator and miner during an accounting period and not the amount understood at the time of the execution of a lease.

Drake v. Berry (Pennsylvania), 102 Atlantic, 315, p. 320.

"MINER'S WEIGHT"—MEANING.

A coal-mining lease gave the lessee the right to mine and carry away 5,000 tons of coal yearly at 10 cents a ton "miner's weight to be the standard." "Miner's weight" is not a fixed unvarying quantity of mine-run material that a miner must produce in order to be paid for mining a ton of coal, the excess being a more or less arbitrary advance against him for refuse and waste in the mine-car content. The failure of a lease to state the number of pounds as a miner's weight would indicate that the amount of the mine-run material which a miner must produce would vary from time to time with the changes in the quality of the material obtained from the mine.

Drake v. Berry (Pennsylvania), 102 Atlantic, 315, p. 320.

VALIDITY OF LEASE—DETERMINATION—JURISDICTION OF COURT.

A lease was executed by tenants in common in the State of Maryland granting the right to operate and mine coal lands and coal mines in the State of Pennsylvania. One of such tenants was an insane person and the court authorized his committee to execute the lease for him. The insane ward had also a trustee who managed his estate. At the time of the execution of the lease the same person was the committee and the trustee for the insane ward. The validity of a lease so signed and its effect upon the title of the coal in the State of Pennsylvania must be determined under the laws and by the courts of that State. The courts of Maryland in an action involving the title to the property in Pennsylvania can not properly determine the question of the title and the rights of the parties under such a lease and do justice to the parties.

Wilmer v. Philadelphia-Reading Coal & Iron Co. (Maryland), 101 Atlantic, 538, p. 542.

PERFORMANCE—UNAVOIDABLE DELAY—EXCUSE.

A coal lease provided that if the lessee ceased for a period of three months to operate the leased mine the lease should be forfeited unless the delay was unavoidable and caused by circumstances beyond the control of the lessee. The lessee did cease to operate the leased mine for a period of more than three months but claimed that the cessation of operations were due to circumstances beyond his control in this, that there was a general strike at the mines, and a mountain slide which covered the tracks over which the coal had to be shipped. The proof showed that the lessee corporation was practically bank-

rupt, its plant in poor condition, its miners restless and uneasy, and few of them at work when the lessee ceased his operations. The slide was of trifling consequences and proved to be a slight obstruction and finally was removed in a few days. "Upon no reasonable view of the case could it be held that there was ever a strike or a slide of such character as to excuse the lessee from the operation of the mines according to the contract."

Matoaka Coal Corp. v. Clinch Valley Min. Co. (Virginia), 93 Southeastern, 799, p. 803.

BREACH OF COVENANT—MAINTENANCE OF COAL PILLARS.

A coal mining lease provided that between the outer boundary lines of the leased premises and the adjacent property there shall be left a solid wall of coal at least 60 feet in thickness that shall not in any manner be broken through without the written consent of the lessor. A third person can not maintain an action for a breach of this covenant in the lease where as complainant he does not show that he was a party to or had any interest in the particular covenant in the lease. The plaintiff could not recover on the ground of an implied covenant for quiet enjoyment where he made no statement of any such claim in his pleading.

Dodson Coal Co. v. Delano (Pennsylvania), 102 Atlantic 126.

COVENANT TO LEAVE PILLARS—MINING WITH CONSENT OF LESSOR.

An adjoining landowner can not complain of a breach of a covenant by a lessee to leave certain pillars in a coal mine, where the condition was that the lessee should not remove or drill through the pillar without the consent of the lessor, and where the lessor gave his consent to the lessee to so mine through the pillar.

Dodson Coal Co. v. Delano (Pennsylvania), 102 Atlantic, 126, p. 127.

EXECUTION BY TRUSTEE OF INSANE PERSON.

A court authorized the committee of an insane person to join with other tenants in common in the execution of a lease of coal mines on the premises. The lease was improperly executed by a trustee under the will through which the tenants in common derived title to the coal. The trustee of such insane person can not after receiving and accepting his ward's full share under the lease and after a long lapse of time, sue and require an accounting and payment for his ward's interest in the coal mined and sold. Under such circumstances the court having jurisdiction of the ward's estate may ratify the unauthorized execution of the lease and do justice to all the parties by denying the trustee the right to recover.

Wilmer v. Philadelphia-Reading Coal & Iron Co. (Maryland), 101 Atlantic, 538, p. 542.

FAILURE OF ONE COTENANT TO JOIN IN LEASE—ACCEPTANCE OF RENTAL—ESTOPPEL.

A number of tenants in common joined in a coal mining lease to another cotenant, who under the lease mined and removed the coal and accounted therefor to his cotenants. One cotenant, who did not join in the lease but who received and accepted and retained his full aliquot part of the rentals, can not afterwards sue and recover the value of his undivided interest on the ground that he did not unite in the lease.

Wilmer v. Philadelphia-Reading Coal & Iron Co. (Maryland), 101 Atlantic, 538, p. 541.

EJECTMENT—DISTRESS NOT REQUIRED.

The Code of Virginia (sec. 2796) requires in actions of ejectment based upon a right of reentry for nonpayment of rents, proof of distress upon the property. But where the amount of the rent due exceeds the value of the personal property of the lessee on the premises the distress is not required.

Matoaka Coal Corp. v. Clinch Valley Min. Co. (Virginia), 93 Southeastern, 799, p. 804.

EJECTMENT—SUBLESSEE FROM LESSEE IN POSSESSION.

In an action of ejectment by a lessor against the assignee of the lessee because of a forfeiture of the lease by reason of the violation of its covenant, a sublessee is a proper but not a necessary party to the action within the meaning of the Virginia Code; but under the provisions of the code he may be named as a party (Virginia Code, sec. 2726). Such a person is a proper party where he is the only party in interest, and where he refused to disclaim in the absence of the original lessee. The failure of the lessor to make the original lessee a party was not a bar to an action even in tort and could only be pleaded in abatement.

Matoaka Coal Corp. v. Clinch Valley Min. Co. (Virginia), 93 Southeastern, 799, p. 805.

FORFEITURE—UNAVOIDABLE DELAY.

The fact that a lessee did not have sufficient funds with which to operate a leased coal mine could not be considered a delay that was unavoidable or caused by circumstances beyond its control, and was not sufficient to prevent a forfeiture under the terms of the lease.

Matoaka Coal Corp. v. Clinch Valley Min. Co. (Virginia), 93 Southeastern, 799, p. 803.

OIL AND GAS LEASES.

CONSTRUCTION—CONDITION OF FORFEITURE.

An oil and gas lease must state the condition upon which a forfeiture can be declared or no forfeiture can be declared.

Smith v. Peoples Natural Gas Co. (Pennsylvania), 101 Atlantic, 739, p. 741.

CONSTRUCTION—TENANT IN COMMON—ROYALTIES.

An oil and gas lease provided for the payment of one-eighth of the oil produced as royalty and required the lessee to carry the lessor's one-sixteenth working interest clear through on the lease. These provisions mean that the lessee shall conduct the operations upon the land without calling on the lessor to contribute to the funds necessary to produce the oil and shall pay to the lessor, in addition to the royalty, one-sixteenth of any profits derived from such operations, as though he was actually a partner.

Paxton v. Benedum-Trees Oil Co. (West Virginia), 94 Southeastern, 472, p. 476.

CONSTRUCTION—PAYMENT OF RENTALS—RIGHT TO FORFEIT.

An oil and gas lease granted to the lessee all the oil and gas in and under the land described. The lessee agreed to drill a well on the premises within four months or thereafter pay to the lessor a stipulated sum quarterly in advance until a well should be drilled or the property surrendered. The lease also provided that if oil was found in paying quantities the lessee was to deliver to the lessor one-sixth of the oil produced, and if gas was found in paying quantities he should pay the lessor at the annual rate of \$200, payable in advance. By the terms of the lease the lessee could at any time remove all of his property, fixtures, etc., and surrender the lease and terminate his liability thereunder. The lessee subsequently assigned his lease to a natural-gas company. No well had been drilled for a period of 10 years, but the lessee and his assignee had paid the stipulated rental sum. In August, 1912, the lessor refused to receive further rentals and demanded a surrender of the lease. The rental for each quarter thereafter was tendered until June, 1913, and the rental due on June 4 of that year was not tendered until June 16, and was declined. In December following the lessor notified the lessee that he declared the lease forfeited for the reason that the rental due June 4, 1913, was not paid. In May, 1915, the lessor began his action to have the lease declared forfeited. The acceptance of the quarterly payments, treated by both parties as rentals, negatived any claim that the contract had either expired or had been rescinded, and up to that time the relation of landlord and tenant existed. The refusal to accept the tender of September, 1912, was on the ground that it was not made in time, an admission that up to that date the contract was a subsisting one and had neither been rescinded nor revoked. As the lease made no provision for forfeiture, under the facts stated the lessor was not in a position to demand and enforce a forfeiture of the lease.

Smith v. Peoples Natural Gas Co. (Pennsylvania), 101 Atlantic, 739, p. 740.

CONSTRUCTION—RIGHTS OF LESSEE AS AGAINST SURFACE OWNER.

The lessee of an oil and gas lease has the right as against a grantee of the surface to enter upon the surface of the land and explore and operate the same for oil and gas, where the common owner of the surface and minerals sold and conveyed the surface, reserving to himself all mineral rights and the right to enter upon the land and to use so much of the surface as may be reasonable for the purpose of extracting the mineral therefrom.

Barker v. Campbell-Ratliffe Land Co. (Oklahoma), 167 Pacific, 468.

PRACTICAL CONSTRUCTION.

Where the terms of an oil and gas lease are clear and explicit, and the meaning is not doubtful, and there is no latent ambiguity, the lease can not be varied by the subsequent conduct of the parties or surrounding circumstances. The parties must be deemed to be bound by the lease, regardless of the results produced.

Jameson v. Chancellor-Canfield Midway Oil Co. (California), 167 Pacific, 369, p. 372.

CONSTRUCTION—"PAYING QUANTITIES."

An oil and gas lease was for a term of five years and as long thereafter as oil or gas was produced therefrom in paying quantities. The production required to effectuate the extension provided for, in the absence of equitable circumstances varying the rule, is that quantity which will bring a reasonable pecuniary return in excess of the cost of production, regardless of any particular amount of profit derivable from the operation of the well.

Barbour, Stedman & Co. v. Tomkins (West Virginia), 93 Southeastern, 1038, p. 1040.

COMPROMISE AGREEMENT—CONSTRUCTION.

A landowner executed an oil lease to certain-named lessees. No development work was done under the lease. Subsequently the landowner executed another lease to other lessees, who immediately began development work, and after they discovered oil the senior lessees began suit for possession of the land and an accounting. Pending suit a compromise was effected and a compromise agreement entered into. In a subsequent action by the senior lessees to recover sums paid the junior lessees for oil prior to the execution of the compromise agreement, the terms of the compromise agreement construed in the light of the situation of the parties at the time it was entered into was sufficient to excuse the junior lessees from liability for payments made them for oil prior to the execution of the agreement.

Guffey v. Smith, 245 Federal, 106, p. 109.

EXECUTION—SIGNING BY LESSEE UNNECESSARY.

The signing of an oil and gas lease by the lessee is not necessary in order to give him the right to sue for a breach of the covenant where there is nothing to show that such signing was contemplated by the parties.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

RIGHTS OF SECOND LESSEE—NOTICE.

An owner of land executed an oil and gas lease thereon and afterwards executed certain extensions of such lease and subsequently executed to a third person an oil and gas lease upon the same land. Such lease named last can not prevail against the former lease and its extensions, unless the lessee of such second lease had no knowledge of the former lease and its extensions or had no such knowledge as would put him upon inquiry and which if followed up would have disclosed the existence of such lease and its extensions.

Swan v. O'Bar (Oklahoma), 167 Pacific, 470, p. 472.

GRANT OF ONE-HALF OF ROYALTIES—LEGAL EFFECT.

An oil and gas lease or conveyance making a grant or reservation of one-half of the royalties, rents, and income from the oil is a grant of one-half of the oil in place.

Paxton v. Benedum-Trees Oil Co. (West Virginia), 94 Southeastern, 472, p. 475.

Overruling Harris v. Cobb, 49 West Virginia, 360, 38 Southeastern, 559.

ROYALTIES—RIGHTS OF TENANTS IN COMMON.

Where one tenant in common takes possession of the joint premises to the exclusion of his cotenant and leases the same to a third party for the purpose of abstracting the oil therefrom conditioned for a specific proportion of the oil to be paid as royalty, the tenant excluded may if he so elect permit the lessee to continue operations under the lease and require him to account for such proportion of the royalties as his interest in the oil in place bears to the whole thereof.

Paxton v. Benedum-Trees Oil Co. (West Virginia), 94 Southeastern, 472, p. 474.

RECEIPT OF OIL ROYALTIES—RIGHT TO GAS RENTALS.

The fact that a lessor of an oil and gas lease received payments of the oil royalties will not prevent him from recovering the gas rentals stipulated in the lease where the well, in addition to producing oil, produced from one to one and a half million cubic feet of gas per day and where by reason of the gas being found in sand above the oil it could have been utilized by the lessee.

Prichard v. Freeland Oil Co. (West Virginia), 93 Southeastern, 871.

WELL PRODUCING OIL AND GAS—RENTALS.

An oil and gas lease reserved as royalty one-eighth of all the oil produced and provided also for the payment of a stipulated sum for each gas well drilled on the premises, payments to be made on each well within 60 days after a well is completed and to be paid yearly thereafter while gas is produced. The right of the lessor to the gas rental does not depend on whether the particular lessee or some operator can market the gas or whether the same is or can not be marketed by him off the premises, but whether the well is a gas well within the proper meaning and intention of the lease. If a well should be productive in both oil and gas in paying quantities, the terms of the lease would reasonably call for payment of the rent for both products.

Prichard v. Freeland Oil Co. (West Virginia), 93 Southeastern, 871.

PURPOSE OF LEASE—DUTY OF LESSEE TO DEVELOP.

All leases of land for the exploration and development of oil and gas are executed by the lessor in the hope and upon the condition, express or implied, that the land will be developed and thoroughly tested. It would be unjust and unreasonable, as well as contrary to the nature and spirit of such a lease, to allow the lessee to continue to hold the leased premises any considerable length of time without making any effort to further develop the land according to the express or implied purpose of the lease.

Dinsmore v. Combs (Kentucky), 198 Southwestern, 58, p. 60.

DUTY TO DEVELOP—PROTECTION FROM DRAINAGE.

The number and location of wells requisite to the performance of a covenant to drill under an oil and gas lease depend upon the character of the leased territory and whether after the discovery of oil or gas there is a duty to sink an additional well or wells depends upon the probabilities arising from the circumstances surrounding the property and whether they will be profitable to the lessee. The lessee is under no duty to operate a lease at loss to himself to make the premises profitable to the lessor. The lessee must bear all the burdens incident to development and if a well is dry he loses its cost; but if it proves rich in either mineral the lessor receives his share but loses nothing in any event. For such reasons the lessee, except where he fraudulently fails or refuses to act when affirmative action is required, must control the prosecution of the necessary operations, but he can not unduly delay operations where clearly the conditions surrounding the property are such as require speedy progress to effect development and to afford protection against drainage.

Jennings v. Southern Carbon Co. (West Virginia), 94 Southeastern, 363, p. 364.

Chambers v. Perrine (West Virginia), 94 Southeastern, 381.

NUMBER OF WELLS NOT SPECIFIED—IMPLIED OBLIGATION TO DRILL
WELLS.

An oil and gas lease provided that the lessee should deliver to the lessor one-eighth of all the oil produced from the leased premises. The lessee was bound to commence operations on the leased land, or on adjoining lands, and push the work with due diligence until a well should be completed, and if the first well drilled should not prove to be a good or producing well the lessee was to surrender the lease or proceed within 60 days thereafter to drill other wells on the leased premises, and if the lessee ceased to drill or operate on the leased premises he should remove the drilling machinery therefrom and the lease should be surrendered. Two wells were drilled by the lessee, one of which was soon exhausted and the other continued to produce a small quantity of oil; producing wells were drilled on adjoining lands, but no other wells were drilled on the leased premises for seven or eight years. Under such a lease where the number of wells to be drilled is not specified there is an implied obligation that the lessee will fully develop the land by sinking a sufficient number of wells to secure to the lessor a reasonable royalty. When oil or gas is found on leased premises in paying quantities, the lessee is bound to diligently work and operate it so as to bring the product to a present market, and thus to promptly yield to the lessor his royalty, and unless the lessee does actually develop the leased land and in good faith diligently operates under the lease he will be deemed to have abandoned the lease and it will be canceled.

Dinsmore v. Combs (Kentucky), 198 Southwestern, 58, p. 60.

ACTION FOR BREACH OF COVENANT—PLEADING.

In an action by the lessee against the lessor in an oil and gas lease for breach of a covenant for possession and quiet enjoyment, the breach of the covenant is sufficiently alleged by an averment that the title and right to possession were not in the defendant but in a third person and that such third person had brought suit against the lessor and lessee to quiet title to the premises and that the lessor had never, in fact, delivered the possession of the premises to the lessee. The complainant under such circumstances is not required to allege that the defendant, the lessor, had failed to protect him according to the covenant where he took upon himself the burden of proving that the defendant had no rights in the property.

Allan v. Guaranty Oil Co. (California); 168 Pacific, 884, p. 888.

BREACH OF COVENANT—FAILURE OF LESSEE TO PERFORM—PLEADING.

An oil and gas lease gave the lessee three months within which to commence operations; but within seven days after the execution of the lease a third person began suit against the lessor and the lessee to

quiet title against both. In a subsequent action by the lessee against the lessor for damages for breach of the covenant for possession and enjoyment the complainant, by alleging that the suit to quiet title was so begun within seven days after the execution of the lease, stated a cause of action without averring performance on his part.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

SUFFICIENCY OF COVENANT FOR POSSESSION.

No particular words need be used in an oil and gas lease in order to constitute a covenant for possession and quiet enjoyment, but the intention of the parties will control. A provision in an oil and gas lease to the effect "that the first party agrees to protect second party against the claims of any party or parties, should any contests ever arise as to the ownership of same," is sufficient, considering the nature of the instrument and the activities to be engaged in thereunder, to show that the lessee should not be disturbed in his possession or use of the land in question.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 888.

BREACH OF COVENANT TO DRILL—DELAY RENTALS.

When an oil and gas lease contains no express covenant, an implied covenant to drill and protect the lines are alone relied on, and the declaration is silent as to whether the delay rentals have been paid, the declaration is insufficient in an action at law. When such a lease for a specified term imposed the alternative duty to drill or pay delay rental, there is no implied covenant for diligent operation merely to make the lease profitable to the lessor, the delay rentals being regarded as sufficient consideration for postponement of such operations.

Chambers v. Perrine (West Virginia), 94 Southeastern, 381, p. 383.

NO IMPLIED COVENANT TO DRILL OFFSET WELLS—DEMAND AND NOTICE NECESSARY.

In the absence of express covenant in an oil and gas lease to drill there is no implied covenant operative within the period of postponement to drill offset wells to prevent drainage through wells on adjoining territory; but there is an implied condition that in the event of such drainage or imminent danger thereof the lessee will, upon demand of the lessor, drill a well on the leased premises for such purpose within the last period for which the delay rental has been or shall be accepted, or commence one within such period and diligently prosecute the work on it, where such demand is accompanied by a notice of the intention to refuse to receive further payments of rentals and to declare a forfeiture of the lease for failure to drill the well on demand.

Chambers v. Perrine (West Virginia), 94 Southeastern, 381, p. 383.

BREACH OF COVENANT FOR POSSESSION—BURDEN OF PROOF.

In an action by the lessee of an oil and gas lease against the lessor for breach of covenant for quiet enjoyment, the plaintiff, the lessee, by yielding to the paramount title of a third person without a prior demand upon the lessor undertook the burden of proving the validity of such paramount title.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

BREACH OF COVENANT FOR POSSESSION—EVICTION—PLEADING.

In an action by the lessee against the lessor of an oil lease for damages for breach of covenant for quiet enjoyment and for failure to deliver possession of the premises to the lessee, the lessee is not required to aver an eviction where he had never in fact had possession of the premises. But an averment that a third person had asserted and maintained a paramount title and the right to possession in a suit by him to quiet the title against the defendant and complainant is the equivalent of an eviction.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

BREACH OF COVENANT FOR POSSESSION—EVICTION—NOTICE OF SUIT.

The real owner of land brought suit against a lessor in an oil and gas lease, who claimed some interest in and a right to lease the premises, and against his lessee, to quiet the title as against the claims of both. A decree for the plaintiff was rendered. In order to constitute such suit the equivalent of an eviction, notice by the lessee to the lessor of the pending suit and a demand to defend the same was not necessary, nor was it necessary that the paramount title should have been established by judgment.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

FAILURE TO DELIVER POSSESSION—DEMAND UNNECESSARY.

An oil and gas lease contained a provision by which the lessor agreed to protect the lessee against the claims of any person if any contest should arise as to the ownership of the premises. In an action for damages for the failure of the lessor to deliver the possession of the premises to the lessee and to recover the consideration paid, a demand upon the lessor for possession before suit was unnecessary, where it had been previously established that the lessor was never the owner or entitled to the possession of the leased premises, as a demand under such circumstances would be futile after a paramount title had been asserted by the real owner.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 887.

DAMAGES FOR FAILURE TO DELIVER POSSESSION—PLEADING—
ESTOPPEL.

In an action by the lessee of an oil and gas lease against the lessor for damages for failure to deliver possession of the leased premises and to recover the consideration paid because of such failure, and where it is averred that the lessor never delivered and never was able to deliver the possession of the leased lands to the complainant and that the complainant has never had possession of any of said lands, the defendant, the lessor, can not object to the insufficiency of the complaint on the ground that it does not aver performance on the part of the lessee, where the ultimate fact that the defendant had prevented the complainant from performing the conditions of the lease could be plainly inferred from the pleading.

Allan v. Guaranty Oil Co. (California), 168 Pacific, 884, p. 886.

BREACH OF COVENANTS—RIGHT TO FORFEIT.

Certain oil and gas leases contained the usual provisions for drilling oil wells and operating the premises for oil and gas for a stated period. The leases also provided that a failure upon the part of the lessee to perform any of the conditions for a period of 30 days after notification "by the parties of the first part" would be a ground of forfeiture. The leases were executed by three lessors, owners as tenants in common of the leased lands. Under these leases the event which may cause the forfeiture is the failure of the lessee to perform any of the conditions embodied in the leases for a period of 30 days after notification. By the express language of the forfeiture clause the notification must be given "by the parties of the first part." It is only upon the giving of this notice and the failure to perform the conditions named that a forfeiture can be declared. The event can not be said to have happened upon notification given by some of the parties of the first part or any number of them less than all. The provision is that even after the notification by all the parties a forfeiture may be brought about only "if said first parties shall so elect." The contract measures the rights of the parties in respect to the notification, and being a contract regarding a forfeiture it is to be strictly construed and its requirements must be fully met before the right depending thereon can be complete. The court is not dealing with rights and remedies secured to the lessors by force of law, but with rights which they secured to themselves by the provisions of their contract. They attempted to lay the foundation for a forfeiture by proceeding under their contract which required the joint action of all the lessors to accomplish that result, and the contract does not permit it to be done by less than all of the lessors. A forfeiture of the leases can not be demanded and enforced by a part only of the lessors.

Jameson v. Chanslor-Canfield Midway Oil Co. (California), 167 Pacific, 369, p. 371.

RIGHT TO FORFEITURE AND RELIEF FROM FORFEITURE.

The courts of Pennsylvania recognize a distinction between a proceeding for the enforcement of a forfeiture of an oil and gas lease and one asking for relief from forfeiture.

Smith v. Peoples Natural Gas Co. (Pennsylvania), 101 Atlantic, 739, p. 741.

FORFEITURE—FAILURE TO DRILL WELLS.

Equity will not ordinarily entertain jurisdiction to enforce a forfeiture for breach of conditions subsequent or of implied covenants in an oil and gas lease to drill wells or to protect the leased premises from drainage.

Chambers v. Perrine (West Virginia), 94 Southeastern, 381, p. 383.

FORFEITURE FOR FAILURE TO DEVELOP—NOTICE REQUIRED.

An oil and gas lease required the lessee to commence operations on the leased land and push the work with due diligence until a well should be completed, and if the first well should not produce oil in paying quantities the lessee should proceed within 60 days to drill other wells, and if he ceased to drill or operate the leased premises or remove his drilling machinery the lease should be surrendered as void. The lessee drilled two wells on the leased premises, one of which produced oil in small quantities and the well was operated for a period of seven or eight years, the lessor receiving and accepting during all of such period the royalties provided for in the lease; but no other wells were drilled on the premises within that period. Forfeiture for nondevelopment or delay is essential to private and public interest in relation to the use and alienation of property, and in no other business is prompt performance of contracts so essential to the rights of the parties, or delay by one party to prove so injurious to the other, as in the matter of oil and gas leases. But an oil lease under the circumstances here shown should be so construed as to effectuate the intention of the parties in the manner that will do justice to the lessor as well as the lessee without arbitrarily canceling it. The lessor in this lease did not at any time during the seven or eight years demand or exact of the lessee that he commence operating for oil or gas, but accepted the annual rentals paid in full discharge of the obligations of the lease. The lessor at the end of any rental period might have declined to accept royalties and required the lessee to further develop the premises. Under such conditions the lessor is required to give notice to the lessee that he will not accept further royalties and permit the land to remain idle and undeveloped, but will require the lessee to execute the lease according to its terms, and if the lessee then refuses in good faith to commence further drilling, the lessor may by an appropriate action forfeit the lease.

Dinsmore v. Comb (Kentucky), 198 Southwestern, 58, p. 60.

GAS IN PAYING QUANTITIES—RIGHT OF GRANTOR TO FORFEIT LEASE.

The lessor of an oil and gas lease giving the right to explore his land for oil and gas can not forfeit the lease merely because he thinks the quantity of gas discovered is not sufficient to constitute a paying well, where the lessee claims it is such a well and is willing to pay the stipulated rent. It is for the lessee to say when acting in good faith whether the gas is produced in paying quantities.

Barbour, Stedman & Co. v. Tompkins (West Virginia), 93 Southeastern, 1038, p. 1040.

JOINT LEASES—JOINT RIGHT—POWER TO FORFEIT.

Certain oil and gas leases contained a covenant whereby the lessee agreed to drill wells for oil and gas upon the leased lands, do the annual assessment work, and take the steps necessary to acquire patent to the lessors for the lands from the United States, operate pumps to obtain the oil and gas and to pay the lessors a stipulated royalty. The lessee was to have full possession of the lands for the purpose of operating the leases. The leases provided that upon failure of the lessee to perform any of the conditions named for a period of 30 days after notification by the lessors to perform such conditions, the leases shall be null and void, if the lessors shall so elect. The leases were executed by three persons as lessors and one was executed by an oil company, the entire capital stock of which was owned by the other lessors. On September 25, 1911, two of the lessors served on the lessee a notice referring to the conditions of forfeiture and to the implied covenants of the leases, requiring the lessee within 30 days to perform the conditions embodied in each of the leases, stating the particulars thereof and that the failure to perform would render the leases null and void. Thereafter on December 6, 1911, the two lessors by written notice to the lessee declared that because of his failure to perform the conditions in the leases as required by the former notice, they did thereby elect to declare said leases null and void and to terminate the same and demanded an immediate surrender of the possession of the property. On failure of the lessee to surrender the property an action was begun by the two lessors named to quiet the title to the premises. The Civil Code of California provides that a right created in favor of several persons is presumed to be joint and this presumption can be overcome only by express words to the contrary. The provision for forfeiture of the leases is a right created in favor of the lessors within the meaning of the civil code and is not a right reserved to them without application of the code provision. There are no words in the provision, express or otherwise, declaring it to be a several right. The intention of the provision was to enable the lessors to procure and extract a faithful performance of the provisions of the leases and on failure so to do to retake the property and there-

fore it was for the benefit of the lessors and is to be strictly interpreted against them. On this theory it was not within the power of the two lessors to declare a forfeiture of the leases and such forfeiture could be declared only by the joint or concurrent act of all the lessors.

Jameson v. Chancellor-Canfield Midway Oil Co. (California), 167 Pacific, 369, p. 370.

LEASE OF INDIAN LANDS—VALIDITY.

By the act of June 7, 1897 (30 Stat., 62, p. 72), the Quapaw Indians were authorized to lease certain lands for a term not exceeding 10 years for mining purposes. An Indian allottee, subject to this statute, leased his land for the purpose of prospecting, mining, drilling, boring or digging for oil, gas, asphaltum, lead, zinc, coal, and copper and all and every kind of valuable minerals for 10 years, with an additional provision that if oil, minerals or any other substances of value were found in paying quantities the privilege of operating should continue so long as oil, minerals or other substances could be produced in paying quantities. The rule of law is that when conveyances or contracts contain conditions some of which are legal and others illegal and they are several and separable as respect consideration and performance, the latter may be disregarded and the former enforced. Under this rule, the lease in question was held to be divisible and the invalidity of the provision for an extension of time for operation can not affect its validity for the 10-year term which was within the statute and valid.

McCullough v. Smith, 243 Federal, 823, p. 829.

INDIAN LEASE—APPROVAL BY COURT AND SECRETARY.

The fact that an oil lease for Indian land was reported to and approved by the court that ordered the lease did not retract the condition precedent established by the order of the court to the effect that the lease must be presented and approved by the Secretary of the Interior; as the report of the lease and its approval were mere prerequisites and preliminary steps to the submission of the lease to the Secretary of the Interior for his action as required by the original order.

Wellsville Oil Co. v. Miller, 243 U. S., 6, p. 13.

INDIAN LANDS—LEASE—APPROVAL BY SECRETARY.

Section 1 of the act of May 27, 1908 (35 Stats., 312), provides that the Secretary of the Interior may remove the restriction on alienation of Indian allottees wholly or in part under such rules and regulations as to the terms of sale and the disposal of the proceeds as he may prescribe. Section 2 provides that leases of restrictive lands for oil, gas, or mining purposes approved by the Secretary of the Interior by rules and regulations approved by him shall be valid. Such leases of lands valuable for their oil, gas, or mineral, result

in the extraction and disposition of the most valuable part of the property and necessarily remove from that part of the property all restrictions upon alienation and if they fail to do so, they would be ineffective and void. When such leases are approved under section 2, they necessarily remove the restriction from the property in part under rules and regulations approved by the Secretary and if restrictions were removed to the same extent under section 1, they would likewise be removed under the rules and regulations approved by the Secretary. It was neither the intent of Congress, nor is it the effect of the provision in section 9, relating to homesteads, to invalidate leases approved by the Secretary under section 2, or to deprive them of the indispensable effect of valid leases, the removal of the restriction on alienation on leaseholds they evidenced and the royalties they provided. As restrictions on alienation may be removed from leaseholds and their royalties either under section 1 or under section 2, it is essential to the validity of the removal under either section that the same or a like removal should have been first sought and procured under the other.

Parker v. Riley, 243 Federal, 42, p. 45.

INDIAN LANDS—RESTRICTION ON ALIENATION—REMOVAL BY SECRETARY.

An act of May 27, 1908 (35 Stats., 312, p. 315), provides that homesteads of allottees enrolled as mixed-blood Indians having half or more than half Indian blood, and all allotted lands of enrolled full-blooded and enrolled mixed-blood of three-quarters or more Indian blood, including minors of the same degree, shall not be subject to alienation or other incumbrance prior to April 26, 1931, except that the Secretary of the Interior may remove such restrictions wholly or in part. Section 2 of the act provides for leases of restricted lands for oil, gas or other mining purposes with the approval of the Secretary of the Interior. Section 9 of the same act provides that if any member of the Five Civilized Tribes shall die leaving issue surviving born since March 4, 1906, the homestead of such allottee shall remain inalienable until April 26, 1931, unless the restrictions against alienation are removed by the Secretary in the manner provided; but if such issue shall die before April 26, 1931, the land shall then descend to the heirs of the original allottee according to the law of descent free from all restrictions. Under these provisions where an allottee died leaving a child born after March 4, 1906, and other heirs, the subsequent approval by the Secretary of the Interior of an oil and gas lease executed by the heirs of the original allottee removed the restrictions on alienation from the leasehold and the royalties thereunder.

Parker v. Riley, 243 Federal, 42, p. 44.

INDIAN LANDS—LEASE AS ALIENATION—RESTRICTIONS REMOVED.

A lease of Indian lands valuable for oil and gas, granting the exclusive right to find and extract all the oil and gas therein, conveys only that part of the oil and gas which the lessee finds and reduces to possession, and not all the fugacious oil and gas in the land; but it nevertheless grants a right and gives the power to the lessee to extract and apply to his own use the most valuable part of the land of the lessor, the oil and gas in the ground; and when the execution of such a lease is followed by the discovery and extraction of valuable deposits of oil and gas thereunder, it not only conveys an incorporeal hereditament, but it effects the removal of the title to the most valuable part of the land of the lessors, as oil and gas in the ground is a part of the land of the owner, and such a lease becomes an alienation of that part of the land of the lessors, which the lessee takes from them, converts into personal property and appropriates to his own use. It follows that a lease of a restricted homestead for oil, gas or other mining purposes under section 2 of the act of May 27, 1908 (35 Stat., 312), is an alienation of that part of the land constituting the homestead which the lease permits the lessee to take from him by the discovery and removal therefrom of such oil, gas or other mineral therein.

Parker v. Riley, 243 Federal, 42, p. 47.

INDIAN LANDS—DESCENT—RIGHTS OF HEIRS.

A life tenant has no right to open mines and no right by virtue of the life estate to the royalties, rents, or profits from oil or gas obtained from mines subsequently opened; but the title to the oil and gas in the ground and the right to the rents, profits and royalties that may in the future be obtained from mines subsequently opened are in the owners of the fee. Under this rule the child of an Indian allottee born since March 4, 1906, has an estate for life in the allotment and this estate is not terminated or changed by the execution of an oil and gas lease approved by the Secretary of the Interior, but the royalties under such lease belong to the heirs to whom the land descended under the laws of the State.

Parker v. Riley, 243 Federal, 42, p. 48.

MINING PROPERTIES.

TAXATION.

INCOME TAX—DEPRECIATION OF MINE.

The word "depreciation" used in the income tax law of 1911 (Laws, 1911, ch. 658), is used in its ordinary and usual sense as understood by business men and means those amounts which business concerns usually charge off in the depreciation account for wear and tear and obsolescence of structures, machinery and personalty used in the business. It would be a strange use of the term to say that where ore is taken from a mine depreciation as generally understood in business circles follows. Evidently the ordinary depreciation of business structures and personalty was in the legislative mind when the act was passed and under the act there can be no deduction for depreciation in value of a mine by reason of taking out the ore.

Phister Land Co. v. City of Milwaukee (Wisconsin), 165 Northwestern, 23, p. 24.
See *Von Baumbach v. Sargent Land Co.*, 242 U. S., 503.

ROYALTIES SUBJECT TO INCOME TAX.

Royalties received under leases of mining property on the ore mined are rentals and though derived from sources without the state are subject to income taxation under the income tax act of 1911 (Laws, 1911, ch. 658), when received by a resident of the State.

Phister Land Co. v. City of Milwaukee (Wisconsin) 165 Northwestern, 23, p. 25.
See *Von Baumbach v. Sargent Land Co.* 242 U. S., 503.

MINERAL INTEREST TAXABLE.

The statute of North Dakota provides that real property for the purpose of taxation includes the land itself and all mines, minerals, and quarries therein. The purpose of the statute is to include any real property, everything which is connected therewith in its use and for which the ground itself is a constituent element. The statute undertakes to say what is defined as real estate but it does not say in whose name the same shall be assessed.

Northwestern Improvement Co. v. Oliver County (North Dakota), 164 Northwestern, 315, p. 318.

ASSESSMENT AND VALUATION.

The owner of certain lands conveyed the same "excepting and reserving unto the grantor, its successors and assigns forever all coal or iron upon or in said lands together with the use of such of

the surface as may be necessary for exploring for and mining or otherwise extracting and carrying away the same." The interest conveyed and the interest reserved are separate and distinct and the interest retained necessarily detracts from the value of the land conveyed and such reservation must be assessed for taxes in the name of the grantor or the owner of the mineral right, where they have taxable value and the value of the mineral rights reserved is easily ascertainable. The payment of taxes by the grantee does not relieve the grantor from the duty of paying taxes on such reservations nor discharge the grantor's taxable obligations.

Northwestern Improvement Co. v. Oliver County (North Dakota), 164 Northwestern, 315, p. 318.

VALUATION OF MINERAL RIGHTS.

Where land has been conveyed with a reservation of all coal or iron and where no mines have been opened and no deposits of coal have been ascertained so as to be able to estimate the amount of mineral present in the land, the difference in the value of the land as sold with and without such reservation of the minerals would measure the value of the grantor's interest in the land. Where the amount of mineral in the land has been ascertained then the value of that mineral together with the value of the right to go upon the lands would be a fair measure of the grantor's interest as a valuation for the basis of taxation.

Northwestern Improvement Co. v. Oliver County (North Dakota), 164 Northwestern, 315, p. 319.

NET INCOME—HOLDING AND SUBSIDIARY CORPORATIONS.

Under the income tax law of 1913 (38 Stats. at Large, 114-166), a holding corporation can not be required to pay income tax on dividends received by it from the accumulated earnings of several subsidiary corporations, whose stock it held, where such accumulations were the undivided earnings of the subsidiary corporations for several preceding years. Such dividends can not be regarded as net income arising or accruing in the preceding calendar year within the meaning of the statute.

Gulf Oil Corporation v. Lewellyn, 242 Federal, 709, p. 713.

PRINCIPAL AND SUBSIDIARY CORPORATIONS.

An oil company as the principal corporation held the stock of several subsidiary companies. They were all engaged in a common enterprise, but the enterprise had several branches and the principal corporation and each subsidiary company attended to its own branch, though the principal corporation united and regulated its subsidiaries. Each company owned its own assets, carried on its own busi-

ness, owed its own debts, paid its own taxes, and enjoyed its own income. Under such circumstances the several companies are not in such relation to each other that the property, obligations, and liabilities of one can be regarded as the property, obligations, and liabilities of any other. Under the excise act of 1909 (36 Stats., 112), each was separately taxed in respect to its own business and under this act, the principal corporation did not include in its own returns the proceeds of the business done by the subsidiaries.

Lewellyn v. Gulf Oil Corp., 245 Federal, 1, p. 6.

Reversing *Lewellyn v. Gulf Oil Corp.*, 242 Federal, 709.

SALE OF MINERALS—TAXATION AS OMITTED PROPERTY.

The owner of land by a proper instrument in writing conveyed for a valuable consideration the underlying coal in his land. The coal after its severance became property capable of definite ascertainment for the purpose of valuation for taxation and was properly added by the auditor of the county as omitted property.

Board, etc. *Sullivan County v. Riggs* (Indiana Appeals), 117 Northeastern, 214, p. 215.

SEVERANCE OF SURFACE AND MINERALS—DEPRECIATION IN VALUE.

Where the owner of lands conveys the minerals therein and thereunder by a written instrument and for a stated consideration, it is the duty of a county auditor when he enters the transfer to diminish the valuation of the surface of the land by the amount of the value of the minerals thus sold and conveyed.

Board, etc. *Sullivan County v. Riggs* (Indiana Appeals), 117 Northeastern, 214, p. 215.

STATE PRIVILEGE TAX..

The statute of Tennessee (Acts 1909, ch. 479, sec. 4), requires any person or corporation having oil depots, storage tanks, or warehouses for the purpose of selling, delivering, or distributing oil and any such person or corporation using a railroad car or railroad depots for such purposes shall pay a certain privilege tax. The privilege tax provided by this section can not be imposed on an Indiana oil refining company that shipped and consigned cars or tanks of oil to a purchaser at Mount Pleasant, Tenn., and where the cars or tanks were billed and were to be shipped to Columbia in the same State where a definite portion of the contents of each tank was to be taken out and delivered to the consignee at Columbia and the cars and tanks with the remainder of the contents should then proceed to Mount Pleasant. The transportation of the tanks destined to Mount Pleasant was not completed when it reached Columbia and the continuity of its movement was not broken by the temporary stop at Columbia.

Western Oil Refining Co. v. Lipscomb, 244 U. S., 348, p. 348.

LIENS.**EXPENSE OF ABATING NUISANCE—ARTESIAN WELLS.**

The statute of New Mexico (secs. 265-268, Code, 1915) declares that an artesian well which is in such condition that water wastes therefrom is a public nuisance and authorizes its summary abatement by the artesian well supervisor. It also provides that the expense of the repairs or other work, including material or labor, shall become a lien on the land where such well is situated on proper notice to be given by the well supervisor. The lien imposed upon the land and well of the owner for the expense of repair or plugging is not upon the theory of benefit to the owner, but is taxed as the cost and expense of abating a nuisance and is within the legislative authority.

Eccles v. Ditto (New Mexico), 167 Pacific, 726, p. 728.

SCHOOL OF MINES.**CONTRACT FOR TEACHERS—INJUNCTION.**

The application of taxpayers to prevent the trustees of the school of mines from carrying out an alleged contract entered into by three of such trustees in their individual capacity and not at a board meeting, to the effect that they would upon certain stated terms employ a third person as president of such school of mines, was denied where the application itself of the suit was to prevent the trustees of the school of mines from electing such person president of the school and where it was conceded that the contract of employment was void. It must be presumed that the trustees when convened in session as a board in accordance with law will properly discharge his duties.

Platt v. Carlton (Colorado), 168 Pacific, 1118.

QUARRY OPERATIONS.

PLEADING AND PROOF.

In an action for damages for injuries received by an employee in a quarry the plaintiff's allegation was that the operator's foreman who was in charge of the workmen gave a negligent order to some of the workmen to turn loose the cable. The proof showed, and the finding was to the effect, that no such order was given. This being the sole allegation of negligence and of the ground of recovery, the finding was necessarily fatal to the plaintiff's right of recovery.

Talley v. Harris Granite Quarries Co. (North Carolina), 93 Southeastern, 995, p. 997.

LIABILITY OF EMPLOYER.

An employee working in a quarry with other employees and injured by reason of the negligence of such coemployees can not recover from the quarry operator, as the operator is not liable to one employee injured through the negligence of his coemployees.

Talley v. Harris Granite Quarries Co. (North Carolina), 93 Southeastern, 995, p. 997.

LEASE—COVENANT TO REMOVE REFUSE.

Quantities of dirt from stripping, broken stone, riprap, and refuse had accumulated in a quarry from its operation at the time of the execution of a lease of the quarry. The lessee knew of such accumulations or refuse and that the removal thereof was necessary to properly operate the quarry. By the terms of the lease the lessee covenanted to cart all dirt accumulating from stripping and operating to a point designated and to remove all refuse, broken stone, riprap, and chimneys as they accumulated and to deposit them where they would not interfere with the future operations of the quarry. Under the known conditions and the terms of the lease the lessee assumed the burden of removing the accumulations and refuse at the time he covenanted to remove similar refuse accumulating from his own future operations. The fact that the lessee covenanted to yield up the premises in as good condition as when entered upon can not be held to release the lessee from the performance of the specific covenant to remove such accumulations and refuse.

East Sioux Falls Quarry Co. v. Wisconsin Granite Co. (South Dakota), 164 Northwestern, 77.

LEASE—COVENANT TO RETURN PREMISES IN EQUALLY GOOD CONDITION.

A lease of a stone quarry requiring the lessee to yield up the premises in as good condition as when the same were when entered upon, loss by fire or inevitable accidents and ordinary wear are excepted. The lessee was not bound to restore the property absolutely in the condition he received it and if any of the property was in a worse condition from misuse or inattention than it was when he received it that depreciation would fall upon the lessee, but if the depreciation was from ordinary wear and tear, from ordinary use in a skillful manner in its operation in the business of quarrying or marketing stone, then the lessee would not be liable for any such loss or depreciation.

East Sioux Falls Quarry Co. v. Wisconsin Granite Co. (South Dakota), 164 Northwestern, 77.

ASSURANCE OF SAFETY BY OPERATOR—EQUAL KNOWLEDGE OF DANGER.

The rule that an employee may rely upon an assurance of safety made by an operator does not apply where the employee is an adult of ordinary intelligence, has had experience in the work, and has knowledge of the danger equal to that of the employer or operator. In such case his reliance upon an assurance of the absence of danger has no justification. The rule does not apply where the employee has an equal or a better knowledge of the danger than that possessed by his employer.

Grey Eagle Marble Co. v. Perry (Tennessee), 197 Southwestern, 674, p. 675.

ASSUMPTION OF RISK—KNOWLEDGE OF DANGER.

An employee working in a quarry may rely upon assurances of safety and proceed with his work unless the danger was so plain that a person of ordinary prudence would see and appreciate it and refuse to take the risk. If the danger was so plain that a person of ordinary prudence would not take the risk, and the employee proceeded with the work with the knowledge of such danger, he must be held to have assumed the risk and can not recover for injuries sustained thereby.

Grey Eagle Marble Co. v. Perry (Tennessee), 197 Southwestern, 674.

DAMAGES FOR INJURIES TO MINERS.

ELEMENTS OF DAMAGES.

MATTERS PROPERLY CONSIDERED IN ESTIMATING DAMAGES.

In an action by a miner for damages for injuries caused by a fall of rock from the roof of the mine due to the alleged negligence of the mine operator, an instruction is not erroneous which authorizes the jury to take into account only the complainant's "crippled and maimed condition, and the nature and extent and duration thereof, the physical and mental pain he has suffered by reason of his said injury, the length of time he was confined to his bed or room, unable to work by reason of such injuries, the diminution, if any, of his earning capacity, and the probable duration of his life."

Peacock Coal Min. Co. v. Crawford (Indiana Appeals), 117 Northeastern, 504, p. 506.

RIGHT TO RECOVER PUNITIVE DAMAGES.

Under an ordinary complaint for damages for injuries to a miner caused by the negligence of the mine operator, it is error for a court to instruct the jury that the plaintiff is entitled to recover both compensatory and punitive damages. But it is harmless where the court immediately corrected the error.

Empire Coal Co. v. Goodhue (Alabama), 76 Southern, 31, p. 32.

RECOVERY OF PUNITIVE DAMAGES.

Under a complaint charging a defective condition of the roof of a mine resulting proximately in injuries to the complainant, and averring that the defendant "grossly and wantonly and recklessly permitted the roof to remain in said defective condition, and plaintiff was proximately injured from said gross and wanton negligence," a jury may award the complainant, in addition to compensatory damages, such damages as in their discretion they see fit to punish the defendant for such action and to deter others in like business from such wrongdoing in the future.

Clinton Min. Co. v. Bradford (Alabama), 76 Southern, 74, p. 79.

PROOF OF STATEMENT OF CONDITION TO PHYSICIAN.

A physician has a right to obtain a history of the patient's case and to form an opinion therefrom which he may give in his testimony in an action by the injured person, and in such action the physician may give his opinion as to the injured person's present condition

and as to the probable cause thereof, and this may be based upon what the injured person stated to the physician when he was examined by him long after the accident and with a view of giving his testimony in the case. But an injured person may not make statements to a physician favorable to his case and upon the trial introduce the physician to prove such self-serving statements; but this rule does not prevent the physician from giving his opinion as to the condition of the injured person and the cause of it.

Stearns Coal & Lumber Co. v. Williams (Kentucky), 198 Southwestern, 54, p. 55.

MORTALITY TABLES AS EVIDENCE.

In an action by a miner for damages for injuries, mortality tables are competent for the purpose of showing the probable length of life of a given person and are merely an aid to the jury, but they are not conclusive. In such a case, the court may properly instruct the jury to the effect that in estimating the loss of the miner's earning capacity they may consider his life expectancy "based on the evidence" and such an instruction is not rendered erroneous by the addition of the words "and upon your own experience and knowledge as to such matters."

Cnkovch v. Success Min. Co. (Idaho), 166 Pacific, 567, p. 570.

DAMAGES NOT EXCESSIVE.

DAMAGES NOT EXCESSIVE—INSTANCES.

In an action by a miner for injuries received while working in a mine, a judgment for \$7,500 is not excessive where it appeared that the miner was 31 years of age, experienced in mining, and was at the time of his injury earning \$3.50 per day, with a life expectancy of 34 years; and where the evidence showed that the injury was permanent and that the miner would never be able to do any labor which required any exercise whatever.

Cnkovch v. Success Min. Co. (Idaho), 166 Pacific, 567, p. 571.

WATER RIGHTS.

APPROPRIATION OF WATER—ABANDONMENT.

The statute of Oregon (sec. 6546 L. O. L.) provides that the right to appropriate water for irrigation and domestic purposes may be abandoned by failure to use such water for a period of one year. But this act does not apply to the taking of water for the purpose of developing the mineral resources of the State and furnishing electrical power. Sec. 6571 fixes the period of nonuser for developing mining and electrical power at two years. The two acts treat of different subjects and each provides its own limit of nonuser as a ground of forfeiture. On abandonment under either statute the water reverts to the public and is subject to other appropriation in order of priority.

Waters of Umatilla River, In re (Oregon), 168 Pacific, 922, p. 924.

* CONTRACT TO SUPPLY WATER—CONSTRUCTION—LIABILITY.

A contract entered into between a water-supply company and a coal-mining company provided that the water company was to furnish the coal company 250,000 gallons of water a day at 5 cents a thousand gallons. The contract further provided that if the quantity of water furnished at the meter should not in any one year at the rate of 5 cents per thousand gallons amount to \$900 or more, the coal company should nevertheless pay to the water company the sum of \$900 for each and every year in which the quantity of water should not equal or exceed the sum of \$900. There is no provision in the contract by which the coal company obligates itself to receive the 250,000 gallons of water per day. This contract does not compel the coal company to receive 250,000 gallons of water per day and it can not be compelled to pay for that amount of water, where there is nothing in the contract that compels the water company to furnish that number of gallons of water per day. Under the terms of the contract the amount which the coal company obligated itself to receive was to be measured by the minimum rental of \$900 per year.

Mountain City Water Co. v. Harleigh-Brookwood Coal Co. (Pennsylvania), 101 Atlantic, 734.

RIGHT TO DRAIN WATER ON LANDS OF OTHERS.

The owner of land adjoining a quarry can not enjoin the owner of the quarry from draining the same and from pumping water from his quarry into a drain through and across the land of the complainant where it appears that for a valuable consideration the quarry owner obtained the right or easement from a prior owner and had expended a large sum of money in putting in a drain and where it also appears that at the time when the quarry owner was preparing to drain the water in a different direction he was requested by the former owner of the land to make the drain across his land, which was the natural water shed, and gave the land owner the privilege of connecting with and using the drain.

Gerard v. Lehigh Stone Co. (Illinois), 117 Northeastern, 698, p. 699.

41311°—18—Bull. 164—11

INTERSTATE COMMERCE.

STATE REGULATION—FREIGHT RATES.

The constitution of Missouri (sec. 12, Art. XII), provides that it shall not be lawful for any railway company to charge a greater amount for the transportation of freight or passengers for a less distance than an amount charged for any greater distance with certain stated exceptions. This section prohibits a railroad company from charging for the shipment of coal in respect of intrastate commerce more for a shorter haul than for a longer one over any portion of its line within the State without regard to direction, circumstances, or conditions. A coal company that has been compelled to pay freight at a rate greater for a short than for a long haul has an absolute right to recover any overcharge so paid.

Missouri Pacific R. Co. v. McGrew Coal Co., 244 U. S., 191, p. 199.

REGULATION BY STATE ACTION.

Interstate commerce consisting of the transportation, sale, and distribution of natural gas is not of a local nature in the State in which it is sold and distributed and is not, even in the absence of action by Congress, subject to burdens or regulations imposed by State action, which are substantial rather than incidental in their nature. A statute or the order of a public-utilities commission fixing a price at which gas, transported from another State, may be sold to the ultimate consumer is in fact a fixing of rates for the transportation of the gas and is a direct burden upon and a direct attempt to regulate interstate commerce.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658, p. 689.

SHIPMENT OF COAL—INTERSTATE AND INTRASTATE FREIGHT RATES.

Cars of coal were delivered by a coal-mining company to a railroad company for shipment in the usual and ordinary way without any direction or request by the coal-mining company as to what particular trains were to haul the cars. The railroad company received and hauled such cars of coal in the usual and ordinary course of its business on the usual trains passing over its road. The trains that hauled the company's cars of coal to points within the same State received and hauled other cars and shipments consigned from points within such State to points without the State, and received cars from points without the State to points within the State, and cars from points without the State through the State to points in other

States. These facts do not justify the railroad company under the constitution of Missouri (sec. 12, Art. XII) in charging a greater freight rate for a short distance than for a greater distance.

Missouri Pacific R. Co. v. McGrew Coal Co., 244 U. S., 191, p. 196.

INTER AND INTRASTATE SHIPMENT—DETERMINATION.

The question whether particular commerce is interstate or intrastate is ordinarily determined by what is actually done and not by any mere billing or plurality of carriers; and where cars or tanks of oil are in fact destined from one State to another, rebilling or reshipping en route does not of itself break the continuity of the movement or require that any part be classified differently from the remainder. It is the essential character of the commerce, not the extent of local or other bills of lading.

Western Oil Refining Co. v. Lipscomb, 244 U. S., 346, p. 349.

CONTINUOUS SHIPMENT—RESHIPMENT IN STATE OF CONSIGNMENT.

A car or tank of oil was shipped by an oil-refining company in Indiana to its consignee in the State of Tennessee. The car was billed to the consignee at a particular point or station for the convenience of the consignee; a part of the contents of the car was there removed by the consignee and the car then rebilled to the consignee to another shipping point. This method was adopted because the carrier refused to permit any stop-over privileges on the oil tanks; but the intention of the parties was that the shipment should go to the consignee at the last shipping point named. The transportation of the merchandise destined to the latter shipping point was not completed when it reached the first point named nor was the continuity of its movement broken by its temporary stop at such first-named place. The journey to the first-named place and the journey from there to the second-named place were not independent each of the other, but in fact and in legal contemplation were connected parts of a continued interstate movement to the latter place. Under such circumstances a State privilege tax can not be imposed for the shipment from the first named point to the second.

Western Oil Refining Co. v. Lipscomb, 244 U. S., 346, p. 349.

PRODUCTION, TRANSPORTATION, AND DISTRIBUTION OF NATURAL GAS.

A corporation engaged in producing gas from wells in Oklahoma and Kansas and transporting it from such wells through pipe lines beginning in Oklahoma and entering the State of Kansas, at which point gas is first distributed and sold to consumers, and is then transported through pipe lines conveying gas from the wells in Oklahoma and Kansas, on through the latter State, with sales and distribution

at different points, the pipe lines and transportation extending on into the State of Missouri, where it is sold to other consumers, is engaged in interstate commerce. The fact that the gas brought from Oklahoma in the pipe lines can not be distinguished from the gas produced and entering the pipe lines in Kansas and that distribution and sales of such mingled gas in the State of Kansas does not destroy the interstate commerce character of the transaction, and the character of the business inheres from the beginning of the journey in Oklahoma to the termination thereof at the burner tips.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658, p. 681.

St. Joseph Gas Co. v. Barker, 243 Federal, 206, p. 212.

ELEMENTS AS APPLIED TO NATURAL GAS.

Interstate commerce as applied to natural gas begins when the gas is delivered to the carrying company for transit from a point in one State to a point in another State or is actually started on its ultimate passage. Interstate commerce in natural gas ends when the shipment reaches its intended destination. A change of carriers or plurality of carriers does not affect the status of the interstate shipment. Change of ownership of the gas during transit does not necessarily affect the status of the shipment. Employment of an agent at the point of destination to effect delivery to the ultimate consumer does not destroy the character of the shipment. The time and place at which the title to the gas passes as between seller and consumer is not controlling upon the character of the shipment. The parties, shipper, carrier, and consumer, may be three separate parties or a less number. The absence of a specific consignee at the time and place the transportation is started does not alter the character of the shipment. The exact destination of the gas need not be fixed at the time the transportation is commenced, if the intent and purpose is to continue the transportation beyond the limits of the State in which it begins. The fact that the transportation is started before a definite order for a specified amount is given is immaterial, as the continual and usual course of business determines the character of the shipment.

Landon v. Public Utilities Commission of Kansas, 242 Federal, 658, p. 683.

PUBLICATIONS RELATING TO MINING LAWS.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

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PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 75. Rules and regulations for metal mines, by W. R. Ingalls and others. 1915. 296 pp., 1 fig.

BULLETIN 90. Abstracts of current decisions on mines and mining, December, 1913, to September, 1914, by J. W. Thompson. 1915. 176 pp.

BULLETIN 101. Abstracts of current decisions on mines and mining, October, 1914, to April, 1915, by J. W. Thompson. 1915. 138 pp.

BULLETIN 118. Abstracts of current decisions on mines and mining, reported from October to December, 1915, by J. W. Thompson. 1916. 74 pp.

BULLETIN 126. Abstracts of current decisions on mines and mining, reported from January to April, 1916, by J. W. Thompson. 1916. 90 pp.

BULLETIN 152. Abstracts of current decisions on mines and mining, reported from January to April, 1917, by J. W. Thompson. 1917. 79 pp.

BULLETIN 159. Abstracts of current decisions on mines and mining, reported from May to August, 1917, by J. W. Thompson. 1917. 111 pp.

TECHNICAL PAPER 138. Suggested safety rules for installing and using electrical equipment in bituminous coal mines, by H. H. Clark and C. M. Means. 1916. 36 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPER-INTENDENT OF DOCUMENTS.

BULLETIN 61. Abstracts of current decisions on mines and mining, October, 1912, to March, 1913, by J. W. Thompson. 1913. 82 pp. 10 cents.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood; and others. 1913. 101 pp., 1 pl., 11 figs. 10 cents.

BULLETIN 79. Abstracts of current decisions on mines and mining, March to December, 1913, by J. W. Thompson. 1914. 140 pp. 20 cents.

BULLETIN 94. United States mining statutes annotated, by J. W. Thompson. 1915. 1,772 pp. In two parts, not sold separately. Cloth, \$2.50 per set; paper, \$2.

BULLETIN 113. Abstracts of current decisions on mines and mining, reported from May to September, 1915, by J. W. Thompson. 1916. 124 pp. 15 cents.

BULLETIN 143. Abstracts of current decisions on mines and mining, reported from May to August, 1916, by J. W. Thompson. 1916. 72 pp. 10 cents.

BULLETIN 147. Abstracts of current decisions on mines and mining, reported from September to December, 1916, by J. W. Thompson. 1917. 84 pp. 10 cents.

TECHNICAL PAPER 53. Proposed regulations for the drilling of oil and gas wells, with comments thereon, by O. P. Hood and A. G. Heggem. 1913. 28 pp., 2 figs. 5 cents.

Bulletin 165

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

BIBLIOGRAPHY OF PETROLEUM AND ALLIED SUBSTANCES IN 1916

BY

E. H. BURROUGHS



**WASHINGTON
GOVERNMENT PRINTING OFFICE
1919**

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BIBLIOGRAPHY OF PETROLEUM AND ALLIED SUBSTANCES, 1916.

By E. H. BURROUGHS.

INTRODUCTION.

This bibliography follows the same general scheme as the bibliography of petroleum and allied substances for 1915.^a The names of the publications read are given in the list that follows. This list is practically the same as that for the 1915 bibliography, except that copies of the German publications, outside of a few scattered numbers, could not be obtained. References to articles in these journals have been taken from such sources as were available and credit has been given to those sources. American and foreign patents have been entered by title, without abstracts. A few minor changes have been made in the scheme of classification, which is, on the whole, the same as that given in the 1915 bibliography.

ACKNOWLEDGMENT.

Acknowledgment is made to Messrs. J. O. Lewis, C. P. Bowie, J. M. Wadsworth, and E. W. Dean, of the petroleum division of the bureau, for assistance in arranging the references under the classification. The classified references were examined and prepared for publication by Miss H. C. McGown, bibliographer.

PUBLICATIONS EXAMINED.

SERIALS.

The following list contains the names of the serials examined in preparing this bibliography and the abbreviations used in the text references:

American Chemical Society, journal.....	Jour. Am. Chem. Soc.
American Gas Light Journal.....	Am. Gas Light Jour.

^a Burroughs, E. H., Bibliography of petroleum and allied substances, 1915: Bull. 149. Bureau of Mines, 1918. 147 pp.

- American Institute of Mining Engineers, bulletin.....Bull. Am. Inst. Min. Eng.
 American Institute of Mining Engineers, transactions...Trans. Am. Inst. Min. Eng.
 American Leather Chemists Association, journal.....Jour. Am. Leather Chemists
 Assoc.
 American Mining Congress, proceedings.....Proc. Am. Min. Congress.
 American Society of Civil Engineers, proceedings....Proc. Am. Soc. Civ. Eng.
 American Society of Mechanical Engineers, journal....Jour. Am. Soc. Mech. Eng.
 American Society of Naval Engineers, journal.....Jour. Am. Soc. Naval Eng.
 American Society for Testing Materials, proceedings Proc. and Year Book Am. Soc.
 and year book. Test Materials.
 Automobile.....Automobile.
 Berichte der Deutschen Chemischen Gesellschaft Ber. Deut. chem. Gesell.
 (Jan., Feb., Mar.).
 Boletín del Petróleo.....Bol. del Petróleo.
 California Academy of Sciences, proceedings.....Proc. California Acad. Sci.
 California Derrick.....California Derrick.
 Canadian Engineer.....Canadian Engineer.
 Canadian Mining Institute, bulletin.....Bull. Canadian Min. Inst.
 Canadian Mining Institute, transactions.....Trans. Canadian Min. Inst.
 Canadian Mining Journal.....Canadian Min. Jour.
 Chemical Abstracts.....Chem. Abs.
 Chemical Society, journal.....Jour. Chem. Soc.
 Chemische Industrie (Jan. and Feb.).....Chem. Ind.
 Chemische Umschau auf dem Gebiete de Fette, Oele, Chem. Umschau.
 Wachse und Harze (May to Nov.).
 Chemiker Zeitung (Jan. 1 to Apr. 26).....Chem. Ztg.
 Cleveland Engineering Society, journal.....Jour. Cleveland Eng. Soc.
 Cornell Civil Engineer.....Cornell Civ. Eng.
 Economic Geology.....Econ. Geol.
 Engineer.....Engineer.
 Engineering.....Engineering.
 Engineering and Contracting.....Eng. and Contr.
 Engineering and Mining Journal.....Eng. and Min. Jour.
 Engineering Magazine (Changed to Industrial Man- Eng. Mag.
 agement, Nov., 1916).
 Engineering News.....Eng. News.
 Engineering Record.....Eng. Rec.
 Engineers' Society of Western Pennsylvania, proceed- Proc. Eng. Soc., Western
 ings. Pennsylvania.
 Franklin Institute, journal.....Jour. Franklin Inst.
 Fuel Oil Journal (Changed to Oil Trade Journal, Fuel Oil Jour.
 Nov., 1916).
 Gas Age.....Gas Age.
 Gas World.....Gas World.
 Génie Civil.....Génie Civil.
 Geological Magazine.....Geol. Mag.
 Geological Society of America, bulletin.....Bull. Geol. Soc. Am.
 Glückauf (Jan. 1-June 3).....Glückauf.
 Good Roads.....Good Roads.
 Horseless Age.....Horseless Age.
 Industrial Management (See Engineering Magazine).
 Institution of Mining Engineers, transactions.....Trans. Inst. Min. Eng.
 Institution of Petroleum Technologists, journal.....Jour. Inst. Petroleum Tech.
 International Marine Engineering.....Int. Marine Eng.

Journal of Electricity, Power, and Gas.....	Jour. Elec. Power and Gas.
Journal für Gasbeleuchtung und Wasserversorgung.	Jour. Gasbel.
Journal of Geology.....	Jour. Geol.
Journal of Industrial and Engineering Chemistry.....	Jour. Ind. and Eng. Chem.
Metallurgical and Chemical Engineering.....	Met. and Chem. Eng.
Mining and Engineering World.....	Min. and Eng. World.
Mining and Oil Bulletin.....	Min. and Oil Bull.
Mining and Scientific Press.....	Min. and Sci. Press.
Municipal Journal.....	Munic. Jour.
Natural Gas Journal.....	Nat. Gas Jour.
National Fire Protection Association, quarterly.	Nat. Fire Protect. Assoc. Quart.
National Petroleum News.....	Nat. Petroleum News.
La Nature.....	La Nature.
Der Oelmotor (Jan.-Mar.).....	Oelmotor.
Oil Age.....	Oil Age.
Oil and Gas Journal.....	Oil and Gas Jour.
Oil and Gas Man's Magazine.....	Oil and Gas Man's Mag.
Oildom.....	Oildom.
Oil, Paint, and Drug Reporter.....	Oil, Paint, and Drug Rep.
Oil Trade Journal (see Fuel Oil Journal).	
Petroleum Age.....	Petroleum Age.
Petroleum Review.....	Petroleum Rev.
Petroleum World.....	Petroleum World.
Petroleum Zeitschrift (Jan.-Sept., except Nos. 12-14).....	Petroleum Ztschr.
Power.....	Power.
Practical Engineer.....	Prac. Eng.
Railway Age Gazette.....	Rwy. Age Gaz.
Railway Review.....	Rwy. Rev.
Resources of Tennessee.....	Resources of Tennessee.
Royal Society of Arts, journal.....	Jour. Roy. Soc. Arts.
S. A. E. Bulletin.....	S. A. E. Bull.
Scientific American.....	Sci. Am.
Scientific American Supplement.....	Sci. Am. Suppl.
Society of Chemical Industry, journal.....	Jour. Soc. Chem. Ind.
Society of Engineers (London), transactions.....	Trans. Soc. Eng.
Standard Oil Bulletin.....	Standard Oil Bull.
Texaco Star.....	Texaco Star.
Washington Academy of Sciences, journal.....	Jour. Wash. Acad. Sci.
Western Engineering.....	West. Eng.
Western Society of Engineers, journal.....	Jour. Western Soc. Eng.
Worcester Polytechnic Institute, journal.....	Jour. Worcester Polytech. Inst.
Zeitschrift für angewandte Chemie (Jan. 4-May 5).....	Ztschr. angew. Chem.

OFFICIAL PUBLICATIONS.

Official publications of the Government that were consulted in preparing this bibliography were as follows:

- Bureau of Mines, bulletins and technical papers.
- Bureau of Standards, circulars and technologic papers.
- Corps of Engineers, professional memoirs.
- Geological Survey, bulletins, professional papers, geologic folios, Mineral Resources of United States for 1915, pt. 2, Non-metals.
- Department of Agriculture, bulletins.
- Department of Commerce, Daily Commerce Reports.

United States Artillery Journal.

Such reports of State geological surveys and mining bureaus and foreign geological surveys and mining bureaus as were published in 1916.

References to foreign patents give the date of application when only one date is given, and dates of acceptance and of application when two dates are given.

SCHEME OF CLASSIFICATION.

The scheme of classification followed in arranging the references is outlined below.

CLASSIFICATION OF SUBJECTS.

MAIN CLASSES.

- 000 General treatises.
- 100 Countries and regions.
- 200 Geology and origin.
- 300 Development and production.
- 400 Transportation, storage, and distribution.
- 500 Properties and their determination.
- 600 Refining and refineries.
- 700 Utilization.
- 800 Legislation and legal regulations.
- 900 Miscellaneous.

DETAILED OUTLINE OF CLASSIFICATION.

- 000 General treatises.
- 100 Countries and regions. (Under each locality follow the classification given under "North America.")
 - 110 North America.
 - 110.001 Historical references and geographic occurrence.
 - .002 Geology and origin.
 - .003 Development and production.
 - .004 Transportation, storage, and distribution.
 - .005 Properties and their determination.
 - .006 Refining and refineries.
 - .007 Utilization.
 - .008 Statistics (includes field development, Crude production, Transportation, storage, and distribution, Refineries and refined products, Consumption, Trade reports, Financial and market statistics, General review of the industry).
 - .009 Legal regulations, economics, maps, miscellaneous.
 - 111 United States.
 - (Subdivided like class 110.)
 - 111.1 Appalachian field.
 - 111.11 Indiana.
 - .12 Kentucky.
 - .13 New York.
 - .14 Ohio.
 - .15 Pennsylvania.
 - .16 West Virginia.
 - .19 Other States (includes Delaware, Maryland, New Jersey, and Virginia).

100 Countries and regions—Continued.

110 North America—Continued.

111 United States—Continued.

111.2 Illinois field.

111.3 Mid-Continent field.

111.31 Kansas.

.32 Louisiana (northern).

.33 Oklahoma.

.34 Texas (eastern and northern).

.39 Other States (includes Arkansas, Iowa, Michigan, Minnesota, Missouri, Nebraska, and Wisconsin).

111.4 Gulf Coast field.

111.41 Louisiana (coastal).

.42 Texas (coastal).

111.5 Rocky Mountain field.

111.51 Colorado.

.52 Montana.

.53 Utah.

.54 Wyoming.

.59 Other States (includes Arizona, Idaho, Nevada, New Mexico, North Dakota, South Dakota).

111.6 Pacific Coast field.

111.61 California.

.62 Oregon.

.63 Washington.

111.9 Miscellaneous.

111.91 Alaska.

.99 Other States (includes Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee).

112 Canada.

113 Mexico.

114 Central America (includes Costa Rica, Guatemala, Honduras, Nicaragua, Panama, and Salvador).

115 West Indies.

115.1 Barbados.

.2 Cuba.

.3 Trinidad.

.9 Other islands (includes Haiti, Porto Rico, and Santo Domingo).

120 South America.

121 Argentina.

122 Peru.

129 Other countries (includes Bolivia, Brazil, the Guianas, Chile, Colombia, Ecuador, Falkland Islands, Uruguay, and Venezuela).

130 Europe.

131 Austria-Hungary.

133 Germany.

134 Great Britain.

136 Roumania.

137 Russia (includes Siberia, Transcaucasia, and Turkestan).

138 Turkey (includes Turkey in Asia).

Countries and regions—Continued.

- 130 Europe—Continued.
 - 139 Other countries (includes Balkan States, Belgium, Denmark, France, Greece, Holland, Italy, Norway and Sweden, Spain and Portugal, and Switzerland).
- 140 Asia.
 - 141 China.
 - 142 India.
 - 143 Japan.
 - 149 Other countries (includes Afghanistan, Arabia, Korea, Persia, and Siam. For Asiatic Russia, *see* Russia in Europe).
- 150 Africa.
- 160 Oceania and Malaysia.
 - 161 Australia.
 - 162 Borneo, Java, and Sumatra.
 - 163 New Guinea (Papua).
 - 164 New Zealand.
 - 165 Philippines.
 - 169 Other islands (includes New Caledonia and Timor).
- 200 Geology and Origin. (*See also* class 100.)
 - 210 General geology.
 - 220 Stratigraphic distribution.
 - 230 Lithology of bituminous rocks.
 - 240 Geologic structure.
 - 250 Origin—theories.
 - 251 Inorganic.
 - 252 Organic.
 - 260 Accumulation.
 - 260.1 Oil and gas reservoir pressures.
 - 270 Applied geology.
 - 270.1 Determination of oil and gas fields.
- 300 Development and production (oil and gas). (*See also* class 100.)
 - 310 Drilling (methods, tools, and equipment).
 - 311 Drilling methods.
 - 311.1 Percussion.
 - . 2 Rotary.
 - 312 Drilling tools.
 - 312.1 Percussion.
 - . 2 Rotary.
 - 313 Equipment.
 - 313.1 Rigs and derricks, and parts thereof.
 - . 2 Power.
 - . 3 Casing and fittings.
 - 313.31 Protection against corrosion.
 - 314 Water and waste, control.
 - 314.1 Cement.
 - . 2 Packers.
 - . 3 Mud fluid.
 - . 9 Other methods.
 - 315 Control of large wells and wells on fire.
 - 316 Use of explosives, shooting.
 - 317 Plugging and abandoning.
 - 318 Records of formation, cost, etc.

300 Development and production (oil and gas)—Continued.**320 Production (methods, equipment, and operations).****321 Flowing oil wells.****322 Pumping oil wells.****322.1 Tools and equipment.****.2 Power.****.3 Operations.****.4 Special pumping methods.****323 Other methods of oil production.****323.1 Bailing.****.2 Swabbing.****.3 Air lifts.****324 Care of producing oil wells.****324.1 Cleaning out.****.2 Heating and steaming, paraffination.****.3 Agitating.****.4 Use of explosives.****.5 Operation of wells producing water.****.6 Operation of wells with loose sand.****.7 Miscellaneous.****325 Gas wells.****328 Records and costs.****330 Production, gathering, and treatment.****331 Oil.****331.1 Gaging and metering.****.2 Gathering systems.****.3 Cleaning and treating for water, B. S., etc.****.4 Disposal of refuse.****332 Gas and vapors.****332.1 Gaging and metering.****.2 Gathering systems.****.3 Compressors and condensers.****.4 Separation from oil or water.****333 Records and costs.****340 Productiveness of oil and gas wells and lands.****341 Natural factors.****341.1 Character of producing strata.****.2 Character of oils.****.3 Gas and gas pressures.****.4 Geologic conditions.****.5 Influence of water.****.6 Causes of decline.****342 Artificial factors, stimulation of production.****342.1 Mechanical.****.2 Spacing of wells.****.3 Economic.****.4 Stimulation of production.****342.41 Decrease of pressure.****.42 Increase of pressure by air or gas.****.43 Use of water.****343 Records and statistics.****343.1 Graphic and other recording methods.****.2 Productiveness of wells.****.3 Productiveness of oil lands.****344 Estimating content of oil and gas lands.**

- 300 Development and production (oil and gas)—Continued.
 - 350 Wastes and conservation.
 - 360 Mining solid bitumens.
 - 390 Financial (appraisements, royalties, contracts, costs, prices).
- 400 Transportation, storage, and distribution. (*See also class 100.*)
 - 410 Transportation.
 - 411 Pipe lines (oil or gas).
 - 411. 1 Construction and maintenance.
 - 411. 11 Protection against corrosion.
 - . 2 Station equipment.
 - . 3 Line equipment and tools.
 - 411. 31 Main lines.
 - . 32 Laterals.
 - . 4 Operations.
 - . 5 Losses.
 - . 6 Records and statistics, maps.
 - . 7 Financial, costs.
 - 412 Tank cars and tank wagons.
 - 412. 1 Construction and maintenance.
 - . 2 Records and statistics.
 - . 3 Financial, costs.
 - 413 Water transportation.
 - 413. 1 Tank steamers.
 - 413. 11 Construction and maintenance.
 - . 12 Records and statistics.
 - . 13 Financial.
 - 413. 2 Barges and other modes of conveyance.
 - 420 Storage.
 - 421 Tanks.
 - 421. 1 Steel and iron.
 - . 2 Concrete.
 - . 3 Wooden.
 - 422 Reservoirs.
 - 422. 1 Earthen.
 - . 2 Concrete-lined.
 - 424 Tank and reservoir equipment.
 - 425 Temporary and small containers.
 - 425. 1 Equipment.
 - 426 Storage and tank farms.
 - 427 Losses.
 - 428 Records, statistics, maps.
 - 429 Financial.
 - 430 Measurement of volumes and weights; gaging and metering.
 - 440 Fire hazards and prevention.
 - 450 Local distribution.
 - 460 Sampling.
 - 470 Legislation and regulation.
 - 490 Financial.
- 500 Properties and their determination. (*See also class 100.*)
 - 510 Physical properties.
 - 511 Molecular weight.
 - 512 Optical.
 - 512. 1 Refractivity.
 - . 2 Polarization.
 - . 3 Photochemical.

500 Properties and their determination—Continued.**510 Physical properties—Continued.**

513 Density (specific gravity) and coefficient of expansion.

514 Thermal.

514.1 Specific heat and latent heats.

.2 Boiling points and vapor pressures. Evaporation, volatility, fractional distillation.

.3 Melting points, crystallization, cold tests, congealing point.

515 Lubricating value.

518 Other properties of liquids: Viscosity, surface tension, capillarity, diffusion, filtration, solubility, fractional precipitation, emulsion, adsorption, compressibility, electrical.

519 Other properties of solids: Hardness, ductility, toughness, consistency, penetrometry, viscosity.

520 Chemical properties.

521 Thermochemical.

521.1 Flash and burning points, ignition points and ignition mixtures.

.2 Calorific power and calorimetry.

.3 Illuminating power, burning qualities and photometry.

.4 Thermal decomposition or "cracking."

521.9 Miscellaneous, including properties such as heat of formation, heat of reaction.

523 Elementary analyses.

523.1 Carbon and hydrogen.

.2 Sulphur.

.3 Nitrogen.

.4 Halogens.

524 Analytical numbers (iodine, bromine, saponification, acetyl, sulphuric acid, absorption, etc.).

525 Hydrocarbons, hydrocarbon derivatives.

525.1 Oxygen compounds.

525.11 Cholesterin.

.12 Petroleum acids and acid content.

.2 Halogen compounds.

.3 Reduced hydrocarbons, hydrogenation and catalysis.

.4 Nitrogen derivatives.

526 Water and solid impurities, sand, B. S., etc.

527 Ash content.

528 Detection of mixtures and adulterants.

529 Miscellaneous and specific tests.

530 Physiological properties.

540 Analytical methods; determination of physical and chemical properties; apparatus and procedure.

550 Power and efficiency tests.

560 Specifications for purchases, etc.

570 Various species and fractions of bitumens and petroleums.

571 Crude oils.

572 Gaseous products, including natural gas.

573 Volatile fractions, including motor oils, gasolines, naphthas, benzines.

574 Illuminating oils.

500 Properties and their determination—Continued.

570 Various species and fractions of bitumens and petroleum—Continued.

575 Lubricating, transformer, and switch oils.

576 Residues.

577 Paraffin, ozokerite, ceresin, vaseline, etc.

578 Asphalt, tars, etc.

579 Shales, miscellaneous solid bitumens, lampblack, and coke.

590 Miscellaneous.

600 Refining and refineries. (*See also class 100.*)

610 Processes and practices.

611 Dehydrating and cleaning.

612 Distillation of liquids.

612.1 Continuous.

.2 Batch.

.3 With inert gases or steam.

613 Cracking of liquids.

613.1 Continuous.

.2 Batch.

.3 With catalyzers.

.4 Gasifying and production of lampblack and coke.

614 Distillation of solids.

614.1 Oil shales.

.2 Peat.

615 Condensation.

616 Treatment to improve properties.

616.1 Chemical.

616.11 Hydrogenation, oxygenation, halogenation, nitration, and catalysis.

.12 Sulphuric and sulphurous acid refining.

.13 By-products and recovery of reagents.

.14 Oxidation, hardening, and saponification.

.15 Bleaching.

616.2 Physical.

616.21 Processes.

616.211 Filtration, refrigeration, and compression.

.212 Extraction.

.213 Emulsification.

.22 Materials.

.23 Apparatus.

616.3 Mechanical.

616.31 Centrifugal.

.32 Crushers and breakers.

620 Specific products and their manufacture.

621 Gasoline, including natural-gas gasoline.

622 Lubricants.

623 Paraffin, vaseline, ceresin, and montan wax.

624 Asphalt.

625 Medicinal oils.

630 Losses, disposal of wastes, fire hazards and prevention.

640 Records and statistics.

650 Construction, equipment and materials.

690 Miscellaneous.

700 Utilization. (*See also class 100.*)**710 Light.**

- 711 Gas illumination.
- 712 Liquid fuel illumination.
- 713 Solid fuel illumination.

720 Heat and power.**721 Steam raising.**

- 721.1 On locomotives.
- .2 On ships.

722 Industrial.

- 722.1 Metallurgical, foundry, and like industries.
- .2 Other uses.

723 Furnaces.**724 Burners and burner appliances.****725 Internal-combustion engines (theory and uses).**

- 725.1 Gas engines.
- .2 Gasoline engines.
- .3 Diesel engines.
- .4 Miscellaneous heavy-oil engines.
- .5 Carburetors, vaporizers, and sprayers.

726 Bitumen fuels for internal-combustion engines.

- 726.1 Fuels for gas and gasoline engines.
- .2 Fuels for heavy-oil engines.

727 Substitutes for bituminous fuels in internal-combustion engines.

- 727.1 Alcohol.
- .2 Benzol.
- .4 Tar and tar oils.
- .9 Other substitutes.

728 Domestic heating.**730 Structural purposes.**

- 731 Pavement and road building, and maintenance.
- 732 Roofing.
- 733 Water proofing and preserving.
- 734 Paints and paint vehicles (including detection of petroleum substitutes in paint vehicles).

740 Lubrication.**750 Medicinal and pharmaceutical uses.****760 Distribution and marketing methods.****770 Consumption, finances, records, and statistics.****780 Fire hazards.****790 Miscellaneous uses.**

- 791 Boiler compounds.
- 792 Insecticides and disinfectants.
- 793 Ore flotation.
- 794 Manufactured fuels.
- 795 Dyes and explosives.
- 796 Soaps.
- 799 Other uses.

800 Legislation and legal regulations. (*See also class 100.*)

- 810 Exploration.
- 820 Development and production.
- 830 Transportation, storage, and distribution.
- 840 Testing and inspection of quality.

- 850 Refining.
 - 860 Utilization and trade.
 - 870 Tariff.
 - 890 Miscellaneous.
- 900 Miscellaneous.
 - 910 Nomenclature.
 - 920 Bibliographies.
 - 930 Organizations and institutions.
 - 940 Expositions and exhibitions.
 - 950 Commerce, trade, and economics.
 - 990 Other articles and publications.

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66. RICH, J. L. Oil and gas in the Birds quadrangle. Bull. 33, Illinois State Geol. Survey, 1916, pp. 105-145. Discusses occurrence of oil and gas and structures favoring oil accumulation. Logs of several wells are given, also descriptions of the oil sands and of various pools.
67. ——— Oil and gas in the Vincennes quadrangle. Bull. 33, Illinois State Geol. Survey, 1916, pp. 147-175. A detailed geological study of the region, describing the various formations and the occurrence of oil and gas. Gives results of investigations of new pools developed since 1911. Suggests areas favorable for further drilling.
68. SAVAGE, T. E. Geologic structure of Canton and Avon quadrangles. Bull. 33, Illinois State Geol. Survey, 1916, pp. 91-99. Describes strata penetrated in drilling; gives representative well logs, and diagrams showing the structure of the beds. Discusses oil and gas accumulations.

DEVELOPMENT AND PRODUCTION.

69. KAY, F. H. Petroleum in Illinois in 1914 and 1915. Bull. 33, Illinois State Geol. Survey, 1916, pp. 71-90. Deals with boring operations, by counties; production statistics for the State; discusses cementing process as practical in Illinois; also possibilities for casing-head gasoline manufacture.

REFINING AND REFINERIES, *see* No. 69; Statistics, *see* Nos. 12-19, 21-34, 69.

MID-CONTINENT FIELD.

GEOLOGY AND ORIGIN.

70. OIL CITY DERRICK. Productive sands of the Mid Continent field. Jan. 14, 1916, pp. 5-6. Gives location of different sands, depth and productiveness of wells in each.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

71. FEDERAL TRADE COMMISSION. Letter of submittal and summary and conclusions of the report of the Federal Trade Commission on pipe-line transportation of petroleum. Washington, Feb. 28, 1916, 27 pp.
72. ——— Report on pipe-line transportation of petroleum. Washington, Feb. 28, 1916, 467 pp. Report of investigation of the investment in pipe lines and cost of operating, covering the five large interstate lines starting from the Mid-Continent field.

See also No. 579.

REFINING AND REFINERIES.

73. JAMES, H. G. Refining conditions in the Mid-Continent field in 1915. Oil and Gas Jour., vol. 14, Jan. 13, 1916, pp. 36-40. Gives figures for gasoline production and fluctuation of prices, and shows growth of refinery industry in 1915.

STATISTICS, *see* Nos. 12-19, 21-34, 73.

KANSAS.

OCCURRENCE.

74. MOORE, P. T. Kansas in role of chief market-maker, or breaker. Fuel Oil Jour., vol. 7, September, 1916, pp. 8-17. Discusses Butler County oil fields, their development, possibilities of new fields, production estimates, the different sands, quality of the oil, market facilities, etc.

DEVELOPMENT AND PRODUCTION.

75. ELECTRICAL WORLD. Electricity in the oil fields. Vol. 68, Dec. 30, 1916, pp. 1298-1299. Shows possibilities in Kansas fields for long-hour central station loads in well pumping, pipe-line pumping and oil heating. Gives cost of operation per month for steam and electric water-pumping equipments.
- GEOLOGY AND ORIGIN, *see* Nos. 74, 111, 318; Legal regulations, *see* No. 96; Statistics, *see* Nos. 2-19, 21-34, 92.

LOUISIANA, NORTHERN.

GEOLOGY AND ORIGIN.

76. MATSON, G. C. The Caddo oil and gas field, Louisiana and Texas. Bull. 619, U. S. Geol. Survey, 1916, 62 pp. Describes geologic structure of the field and occurrence of oil and gas; gives analyses. Contains well logs and geologic and topographic maps.

UTILIZATION.

77. FUEL OIL JOURNAL. Texas-Louisiana railroads' consumption of fuel oil in 1915. Vol. 7, February, 1916, pp. 60-62. Gives statistics for the year. Over 11,000,000 barrels of oil were used.

STATISTICS.

PRODUCTION.

78. Oil Trade Journal. Monthly statement of production, by districts. *See also* Nos. 12-19, 21-34, 77.

MAPS AND PROPERTIES, *see* No. 76.

OKLAHOMA.

GEOLOGY AND ORIGIN.

79. FATH, A. E. An anticlinal fold near Billings, Noble County, Oklahoma. Bull. 641, U. S. Geol. Survey, 1916, pp. 121-133. The geology of the anticline is described relative to possibilities of oil and gas, which are found about 20 miles from the anticline. Gives well records.
80. HEALD, K. C. The oil and gas geology of the Foraker quadrangle, Osage County, Oklahoma. Bull. 641, U. S. Geol. Survey, 1916, pp. 17-47. Discusses topography, stratigraphy, and structure; also, occurrence and accumulation of oil and gas.
- 80a. WEGEMANN, C. H. The Duncan gas field, Stephens County, Oklahoma. U. S. Geol. Survey Bull. 621, 1916, pp. 43-50. A study of the stratigraphy and structure of the field and the occurrence of the oil and gas. Gives analyses of gas from this field.

- 80b. ——— Loco gas field, Stephens and Jefferson counties, Oklahoma. U. S. Geol. Survey Bull. 621, 1916, pp. 31-42. Gives history of development of the field, its stratigraphy and structure. Discusses occurrence of the oil and gas and their origin and analyses.
81. ——— Notes on the gas fields of central and southern Oklahoma. Bull. 629, U. S. Geol. Survey, 1916, pp. 121-128. Discusses future supply of gas to Dallas and Fort Worth, Texas. Describes Checotah and Ada gas fields, and pools in Carter and Stephens counties. (*See also* No. 102.)
- See also* Nos. 93, 111, 317, 318.
- 81a. WEGEMANN, C. H., AND HEALD, K. C. The Healdton oil field, Carter County, Oklahoma. U. S. Geol. Survey Bull. 621, 1916, pp. 13-30. Bull. 621-B, 1915. Gives a short history of development of field, its location, topography and drainage, stratigraphy and structure, and geologic history. Gives also the sources and occurrence of oil and gas in the field. A table of analyses of the oil shows its refining qualities.
- 81b. ——— The Lawton oil and gas fields, Oklahoma. U. S. Geol. Survey Bul. 621, 1916, pp. 71-85. Presents a geologic study of the field, its stratigraphy, structure, etc., position of the oil sands, origin of the oil and gas. Analysis of the gas is given. Gives occurrences of oil, gas and asphalt in the vicinity of the Wichita Mountains.

DEVELOPMENT AND PRODUCTION.

82. HUNTER, J. L. Healdton oil pool, Oklahoma. Oil and Gas Man's Mag., vol. 11, January, 1916, pp. 309-319. Gives history of early drilling.
83. NATIONAL PETROLEUM NEWS. Claims success for "mudding" in Oklahoma oil fields. Vol. 8, May, 1916, 87-88 pp. Report of conservation committee of the Natural Gas Association of America; discusses advantages of mudding.
84. POLLARD, J. A. Use of rotary system in Blackwell field, Oklahoma. Oil and Gas Jour., vol. 14, March 30, 1916, p. 27. Gives advantages of the rotary over the circulator system.
85. SARCHET, C. M. New methods of conservation. Nat. Gas Jour., vol. 10, February, 1916, pp. 73-74. Describes several drilling methods used in the Shamrock and Blackwell fields, Oklahoma. Explains advantages of the mudding or lubricating system. With the circulator system a string of casing over a thousand feet long can be carried. The rotary system enables the gas sands to be shut in and although requiring more men permits quicker drilling and saves money.
- See also* Nos. 340, 478, 491.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

86. OIL AND GAS JOURNAL. Pipe-line construction in Oklahoma in 1915. Vol. 14, January 13, 1916, pp. 43-44. Gives miles of line laid in different fields. Table shows miles laid by each company during 1915.
87. ——— Steel storage built in Oklahoma. Vol. 14, Jan. 13, 1916, p. 63. Gives cost of a tank and list of companies in Oklahoma owning steel storage of 55,000-bbl. capacity.
88. SARCHET, C. M. Concrete tanks for storing oil, replacing steel in Oklahoma. Manufac. Rec., vol. 70, Nov. 2, 1916, p. 65. Concrete tanks reduce rates on insurance. Cost of building steel tanks is given; also storage statistics and value of the oil in the Mid-Continent field.
- See also* Nos. 106, 552, 615.

REFINING AND REFINERIES.

89. **FUEL OIL JOURNAL.** List of casing-head gasoline plants in Oklahoma, with their approximate daily output in gallons. Vol. 7, February, 1916, p. 132.
90. **JAMES, H. G.** Oklahoma leads in casing-head gasoline. *Oil and Gas Jour.*, vol. 14, Feb. 24, 1916, pp. 27-28. Statistical review of the industry in Oklahoma.
91. **WHITNEY, R. H.** Increasing value of casing-head gasoline. *Oil and Gas Jour.*, vol. 14, May 11, 1916, pp. 28, 34. Reviews growth of the industry in Oklahoma and gives statistics of cost, production, etc.
- PROPERTIES AND THEIR DETERMINATION, see No. 478.**

STATISTICS.

92. **MOORE, P. T.** Oklahoma the market-maker. *Fuel Oil Jour.*, vol. 7, February, 1916, pp. 8-5, 8-9, 12-13. A statistical review of production in the Oklahoma and Kansas oil fields.
93. **SHANNON, C. W.** Handbook on the natural resources of Oklahoma. *Okl. Geol. Survey*, Sept., 1916, 96 pp. Reviews the geology of the State and gives general information concerning the natural resources, including asphalt, natural gas and petroleum. Statistics of production are also given.
- See also Nos. 12-19, 21-34, 89-91.*

LEGAL REGULATIONS.

94. **OKLAHOMA CORPORATION COMMISSION.** Eighth and ninth annual reports for the years ending June 30, 1915 and June 30, 1916. Oklahoma City, 1916, 490 pp. Reviews the work of the Commission in the conservation of oil and gas in the State and contains orders issued in regard to oil and gas.
95. **MANNING, V. H.** Conservation of natural gas. *Proc. Nat. Gas Assoc. Am.*, vol. 8, 1916, pp. 72-80; discussion, pp. 80-82; *Nat. Gas Jour.*, vol. 10, June, 1916, pp. 225-229. Summarizes the work of the U. S. Bureau of Mines in the conservation of natural gas, particularly in Oklahoma, and of the resulting legislation in Oklahoma toward this end.
96. **OIL AND GAS JOURNAL.** Oil tax laws of Oklahoma denounced. Vol. 15, Oct. 26, 1916, p. 28. A protest against existing laws in Oklahoma and brief statements of the oil tax methods of Indiana, Kentucky, Ohio, Pennsylvania, West Virginia, Kansas, Texas, California, and Wyoming.
97. **UNITED STATES CONGRESS, SENATE, COMMITTEE ON INDIAN AFFAIRS.** Oil lands in the Osage Reservation. 64th Cong., 1st sess., Rept. No. 164, Feb. 23, 1916, 59 pp. Reports a Senate resolution requesting the Secretary of the Interior to refrain from action on the disposition of certain Osage lands for a period of two years, and authorizing an investigation of the subject of leasing such lands. Contains regulations governing the leasing of Osage lands for oil and mining purposes, approved Aug. 26, 1915, reports of conferences on the subject with the Osage tribal council, etc.
98. **UNITED STATES OFFICE OF INDIAN AFFAIRS.** Regulations to govern oil and gas operations on restricted Indian lands in Oklahoma, approved Oct. 20, 1915, and amended Mar. 15, 1916. Washington, 1916, 8 pp.
- See also No. 491.*

TEXAS, EASTERN AND NORTHEASTERN.

GEOLOGY AND ORIGIN.

99. **DUMBLE, E. T.** The geology of Texas. The Rice Institute Pamphlet, vol. 3, Apr., 1916, pp. 125-204. Discusses geologic history of the State and the

- uniformity of Texas formations with those of other regions, character and extent of deposits, and the geographic and geologic occurrence of materials of economic value, including oil, gas, asphalt, and shale.
100. MATSON, G. C. Gas prospects south and southeast of Dallas. Bull. 629, U. S. Geol. Survey, 1916, pp. 77-119. Gives a geological study of the region in order to determine the quantity of gas available for the future use of the city. General statements are made as to the occurrence, pressure, and accumulation of natural gas, and a detailed account of its occurrence in the Mexia-Groesbeck field is given. Discusses probable future capacity of the field and the probable opening of new producing sands near by. Numerous well logs, charts, etc., are also given. (*See also* No. 102.)
 101. SHAW, E. W. Gas in the area north and west of Fort Worth. Bull. 629, U. S. Geol. Survey, 1916, pp. 15-75. Describes geography, stratigraphy, and geological structure of region and also of the Petrolia field in detail. Conditions favorable for the finding of new pools are given, also numerous well logs. Conclusions are drawn as to capacity of the field in the future and suggestions made as to how the capacity may be increased.
 102. SHAW, E. W., MATSON, G. C., AND WEGEMANN, C. H. Natural gas resources of parts of north Texas. Bull. 629, U. S. Geol. Survey, 1916, 126 pp. Gives results of an investigation to determine the sufficiency and prospective duration of the gas reserves of the cities of Dallas and Fort Worth. (*See also* Nos. 81, 100, 101.)
 103. UDDEN, J. A., BAKER, C. L., AND BÖSE, EMIL. Review of the geology of Texas. Univ. Texas Bull. 44, 1916, 153 pp. Describes in detail the physiography and geology of the State, and gives its geologic history. Describes, also, the economic minerals and the occurrence of oil, gas and asphalt.
 104. UDDEN, J. A., AND BYBEE, H. P. The Thrall oil field. Univ. Texas Bull. 66, 1916, pp. 7-78. Gives a detailed geological study of the region, also analyses of the oil and statistics of production. Describes difficulties caused by the presence of paraffin in the wells. An appendix contains detailed well data. (*See also* Nos. 107, 108.)
- See also* Nos. 76, 81.
- 104a. WEGEMANN, C. H. A reconnaissance in Palo Pinto County, Texas, with special reference to oil and gas. U. S. Geol. Survey Bull. 621, 1916, pp. 51-59. Results of investigation to determine whether anticlines existed which might have influenced the accumulation of oil, and to discover areas where drilling might be successful. Studies topography, stratigraphy, and structure of the region.
 - 104b. ——— A reconnaissance for oil near Quanah, Hardeman County, Texas. U. S. Geol. Survey Bull. 621, 1916, pp. 109-115. Gives results of examination of this area to determine geologic structure and the presence or absence of anticlines which might be effective in producing oil or gas accumulations. No definite conclusion reached as to whether oil is present in commercially paying quantities, though the structure seems favorable.

DEVELOPMENT AND PRODUCTION.

105. RITCHIE, N. E. Texas gas should be conserved. Oil and Gas Jour., vol. 14, Jan. 27, 1916, p. 28. Discusses urgent need for law to prevent waste. Gives causes of waste and how to avert them.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

106. WELCH, W. M. Natural gas resources and supplies (north Texas and southern Oklahoma). Nat. Gas Jour., vol. 10, May, 1916, pp. 187-194.

Results of cooperative investigation by the Bureau of Mines and the cities of Dallas and Fort Worth relative to deposits of natural gas. Discusses means required to deliver supply from the field to the two cities. Report also discusses present and future demands and pipe-line facilities, and the adequacy of present or possible future sources of supply.

PROPERTIES AND THEIR DETERMINATION.

107. SCHOCH, E. P. Ozokerite from the Thrall oil field. Univ. Texas Bull. 66, 1916, pp. 79-81. Gives results of an examination of the waxy material obtained with the petroleum of this field, proving it to be fine ozokerite, free from paraffin. (*See also* No. 104.)
108. SCHOCH, E. P., AND READ, W. T. The chemical composition of the petroleum obtained at Thrall, Tex. Univ. Texas Bull. 66, 1916, pp. 83-88. Gives results of examination of seven samples of Thrall oil, and briefly considers other Texas oils as reported by previous investigators. (*See also* No. 104.)

See also No. 76.

UTILIZATION.

109. BURDICK, R. H. Performance of Diesel-engine plants in Texas. Elec. World, vol. 67, Mar. 11, 1916, pp. 587-592. Discusses fuel and lubricating oil requirements, and engine maintenance. Gives costs and other operating data for eight stations.

See also No. 77.

STATISTICS.

PRODUCTION.

110. Oil Trade Journal. Monthly statement of production, by districts. *See also* Nos. 12-19, 21-34, 77.

LEGAL REGULATIONS, *see* No. 493; Maps, *see* No. 76.

NEBRASKA.

GEOLOGY AND ORIGIN.

111. BARBOUR, E. H. The natural fuels of Nebraska. Nebraska Geol. Survey, vol. 4, pt. 25, 1916, 7 pp. Discusses oil and gas prospects of the southeastern part of the State where the structure is in continuity with that of the oil fields of Oklahoma and Kansas.

IOWA.

UTILIZATION.

112. WAGNER, H. W. A study of oil engines in Iowa power plants. Iowa State College of Agric. and Mech. Arts, Eng. Exper. Sta. Bull. 42, 1916, 159 pp. Gives results of tests of engines in electric light and power plants relative to fuel consumption. Statistics are given, including cost data for various types of engines.

GULF COAST FIELD.

OCCURRENCE.

113. WILSON, L. M. Petroleum and natural gas; a short treatise on their early history, origin, distribution, accumulation, and surface conditions. Houston, Texas, 1916, 64 pp. Relates especially to the Gulf Coast country. *See also* 214b.

GEOLOGY AND ORIGIN.

114. MOORE, W. C. Indications of oil in the Gulf Coast country; what they are and how to know them. Houston, Texas, 1916, 12 pp. Explains various surface indications of oil and gives information as to location, surface and underground conditions of the present known fields.

See also No. 113.

PROPERTIES AND THEIR DETERMINATION.

115. HEYNE, H. R. Comparison of Gulf Coast lubricating oils with paraffine base lubricants. Fuel Oil Jour., vol. 7, Feb., 1916, pp. 140-142. Discusses viscosity and its importance in lubrication. Gives practical tests of these oils as to their lubricating efficiency, internal combustion engine lubrication, their flash points, cold tests, chemical properties, etc.

STATISTICS *see* Nos. 12-19, 21-34.

LOUISIANA, COASTAL.

REFINING AND REFINERIES.

116. SMITH, C. E. "Mexpet" refinery at Destrehan, Louisiana. Pan-American Rec., vol. 1, September, 1916, pp. 10-12; October, 1916, pp. 13-14; November, 1916, pp. 13-14. Gives general description of the plant and its construction.

STATISTICS.

FIELD DEVELOPMENT AND PRODUCTION.

117. Oil Trade Journal. Monthly statement of production, by districts, and Gulf Coast drilling operations.

LIST OF NEW INCORPORATIONS.

118. Fuel Oil Journal. Monthly list of new oil and gas companies.

See also Nos. 12-19, 21-34.

UTILIZATION, *see* No. 77.

TEXAS, COASTAL.

DEVELOPMENT AND PRODUCTION.

119. HAZLETT, A. J. Ingenious method used to extinguish burning gusher at Humble, Texas. Fuel Oil Jour., vol. 7, March, 1916, pp. 78-79. Tells how a pit 75 feet in diameter was dug 100 feet from the burning well and the burning oil was driven by steam and water into this pit through a section of smoke stack and a ditch 4 feet wide, roofed with corrugated iron and covered with dirt.

See also No. 105.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

120. SAFETY ENGINEERING. Gasoline tank fire. Vol. 32, Sept., 1916, pp. 140-144. Gives data on burning and extinguishing of gasoline tanks of Gulf Refining Co., at Port Arthur, Tex., July 19, 1916.

STATISTICS.

FIELD DEVELOPMENT AND PRODUCTION.

121. Oil Trade Journal. Monthly statement of production, by districts, and the Gulf Coast drilling operations.

See also Nos. 12-19, 21-34, 77.

GEOLOGY AND ORIGIN, *see* Nos. 99, 103; Occurrence, *see* No. 90; Utilization, *see* No. 77; Legal regulations, *see* no. 493.

ROCKY MOUNTAIN FIELD.

COLORADO.

OCCURRENCE.

122. DeBEQUE, G. R. The bituminous shale industry in northwestern Colorado. Eng. and Min. Jour., vol. 102, Dec. 9, 1916, pp. 1011-1012. Gives extent of the Colorado oil-shale area, occurrence of the shale, its properties and possibilities.

GEOLOGY AND ORIGIN.

123. DAVIS, C. A. Some fossil algae from the oil-yielding shales of the Green River formation of Colorado and Utah. Proc. Nat. Acad. Sci., vol. 2, Mar. 15, 1916, pp. 114-119. Bull. Geol. Soc. Am., vol. 27, March, 1916, pp. 159-160, abstract. Gives results of a microscopic examination of the oil shales.

124. WINCHESTER, D. E. Oil shale in northwestern Colorado and adjacent areas. Bull. 641-F, U. S. Geol. Survey, 1916, 60 pp. Describes geologic structure of the region. Gives tests to show oil obtainable from the shale. Describes apparatus used, and gives tabulation of results.

See also No. 122.

PROPERTIES, *see* Nos. 122, 124; Statistics, *see* Nos. 12-19, 21-34.

MONTANA.

GEOLOGY AND ORIGIN.

125. BOWEN, C. F. Possibilities of oil in the Pocupine dome, Rosebud County, Montana. Bull. 621, U. S. Geol. Survey, 1916, pp. 61-70. Gives a detailed geologic study of the region. Systematic drilling necessary to show presence of oil and gas.

126. CALVERT, W. R. Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana, with special reference to coal and oil. Bull. 641, U. S. Geol. Survey, 1916, pp. 199-214. Gives geologic study of the region, its stratigraphy and structure, and prospects for finding oil.

127. STEBINGER, EUGENE. Possibilities of oil and gas in north-central Montana. Bull. 641, U. S. Geol. Survey, 1916, pp. 49-91. Reviews the geologic structure; formations similar to those of nearby fields.

UTAH.

OCCURRENCE.

128. HIGGINS, W. C. The ozokerite deposits of Soldier Summit, Utah. Salt Lake Min. Rev., vol. 18, Sept. 30, 1916, pp. 15-18. Gives properties and

- uses of ozokerite as found in Utah, and of its refined product, ceresin. Describes its mode of occurrence and development of the field.
129. HOWARD, L. O. Ozokerite in Utah. *Min. and Sci. Press*, vol. 112, June 17, 1916, pp. 907-911. Describes deposits in Galicia and Utah. Gives methods of purification, properties, and uses of ozokerite products.
130. IRELAND, J. B. Oil shale industry planned for Utah. *Salt Lake Min. Rev.*, vol. 17, March 30, 1916, pp. 14-15. Shale beds are situated in north-eastern Utah and northwestern Colorado. Discusses value of distillation products of shale, including gas and ammonia. Describes John D. Scott process of distilling oil from shale. The retort has three chambers, the preheater, the eduction, and the cooling. Each chamber contains 10 trays with perforated bottoms, 6 inches apart, one above the other. Loading and moving of trays is done by machinery. Treatment requires $4\frac{1}{2}$ hours. Cost is given.
131. ROBINSON, H. M. Ozokerite in central Utah. *Bull. 641, U. S. Geol. Survey*, 1916, pp. 1-16. Gives location, history, and geology of the field, also, composition, properties, mining, and uses of the material.

UTILIZATION.

132. PALMER, ELIHU. Recent uses of Utah elaterite. *Eng. and Min. Jour.* vol. 102, Nov. 11, 1916, p. 856. Elaterite or "mineral rubber" is used in solution as a poreless, waterproof veneer for wood, iron, steel, tin, leather, rubber, cork, concrete, and other substances.
- See also Nos. 128, 129, 131.

GEOLOGY AND ORIGIN, see Nos. 123, 124, 128, 129, 131; Properties, see Nos. 124, 128, 129, 131; Refining and refineries, see Nos. 129-131.

WYOMING.

OCCURRENCE.

133. HERRICK, J. P. Pilot Butte Dome appears promising. *Oil and Gas Jour.*, vol. 15, Sept. 14, 1916, p. 32. Reviews field developments in Wyoming district.
134. LUPTON, C. T. Oil and gas near Basin, Big Horn County, Wyoming. *Bull. 621, U. S. Geol. Survey*, 1916, pp. 157-190. Gives history of field from the first discovery of oil in 1884. Presents stratigraphy and structure in detail, location of oil and gas wells, analyses of oil, and logs of several wells.
135. OIL AND GAS JOURNAL. Past history of oil in the State of Wyoming. Vol. 15, Nov. 16, 1916, pp. 26, 31. Short account of the discovery of oil in the State.

GEOLOGY AND ORIGIN.

136. CONDIT, D. D. Relations of the Embar and Chugwater formations in central Wyoming. *Prof. Paper 98, U. S. Geol. Survey*, 1916, pp. 263-270. Gives detailed geologic description of the Embar formation in which petroleum has been found in the Wind River basin.
137. DARTON, N. H. Sedimentary rocks (of the North Laramie Mountains, Wyoming). *Bull. 626, U. S. Geol. Survey*, 1916, pp. 53-56. Gives a detailed geologic description.
138. HARES, C. J. Anticlines in central Wyoming. *Bull. 641, U. S. Geol. Survey*, 1916, pp. 233-279. Results of a detailed study of the formations of this region, its folds and domes, to ascertain the possibilities of oil and gas. Conclusion is that there are favorable conditions for the accumulation of oil and gas and that thorough prospecting has not been made.

- 138a.** ——— Stratigraphic relations of some of the Cretaceous and Tertiary formations of the Hanna and Powder River basins with those of the Wind River basin. *Jour. Wash. Acad. Sci.*, vol. 6, May 4, 1916, pp. 255-256 (Abstract).
- 139.** **HERRICK, J. P.** Description of the Salt Creek oil field, Wyoming. *Oil and Gas Jour.*, vol. 15, Aug. 31, 1916, pp. 25-26. Describes geologic structure, occurrence of the oil, development, working conditions, storage facilities, etc.
- 140.** **JOHNSON, A. A.** Wyoming as an oil state. *Oil and Gas Jour.*, vol. 15, Dec. 7, 1916, p. 30. A short review of the geological characteristics of the State and prediction of great oil development there.
- 141.** **LUFTON, C. T.** Notes on the stratigraphic and structural relations in southern and eastern Bighorn Basin, Wyoming. *Jour. Wash. Acad. Sci.*, vol. 6, May 19, 1916, pp. 310-311, abstract. Points out prominent features.
- 142.** **TRUMBULL, L. W.** The effect of structures upon the migration and separation of hydrocarbons. *Bull. 1, Wyoming Geol. Survey Sci. ser.*, 1916, pt. 2, 11 pp. Describes in tabular form the structure of the various Wyoming fields. Also, discusses the formation of domes containing oil or gas, applying the theories formed to some of the domes of the State.
- 143.** ——— The light oil fields of Wyoming. *Bull. 12, Wyoming Geol. Survey*, 1916, 2nd ed., 12 pp. Discusses the light oils found in Cretaceous strata. Gives list of these fields, their structure, etc. Also gives depth to the most productive sand in the more important fields. The quality of the oil and possibilities of new fields are discussed.
- 144.** ——— Petroleum in granite. *Bull. 1, Wyoming Geol. Survey Sci. ser.*, 1916, Pt. 1, 16 pp. Describes an occurrence of petroleum in granite and associated crystalline rocks in the central part of Wyoming, and gives an explanation based on the geologic history of the region.
- 145.** **WEGEMANN, C. H.** The discovery of Wasatch fossils in the so-called Fort Union beds of Powder River Basin, Wyoming, and its bearing on the stratigraphy of the region. *Jour. Wash. Acad. Sci.*, vol. 6, May 4, 1916, pp. 254-255, abstract.
- 146.** **ZIEGLER, VICTOR.** The Pilot Butte oil field. *Bull. 13, Wyoming Geol. Survey*, 1916, 39 pp. Gives a detailed geologic study of the field. Describes oil wells and discusses future prospects, which are considered good.
- See also* Nos. 124, 134.

DEVELOPMENT AND PRODUCTION, *see* No. 139; **Transportation**, etc., *see* No. 139; **Properties**, *see* Nos. 134, 143, 146; **Statistics**, *see* Nos 12-19, 21-34; **Legal regulations**, *see* No. 96.

ARIZONA.

UTILIZATION.

- 147.** **ENSIGN, O. H.** Hydroelectric irrigation in Arizona. *Jour. Elec. Power and Gas*, vol. 36, Feb. 5, 1916, pp. 105-108. Contains cost figures and comparisons of hydroelectric, steam, oil and gas power.
- See also* No. 985.

PACIFIC COAST FIELD.

CALIFORNIA.

GEOLOGY AND ORIGIN.

- 148.** **DICKERSON, R. E.** Stratigraphy and fauna of the Tejon Eocene of California. *California Univ. Dept. of Geology, Bull.*, vol. 9, May 2, 1916, pp. 363-524.

149. ENGLISH, W. A. Geology and oil prospects of Cuyama Valley, California. Bull. 621, U. S. Geol. Survey, 1916, pp. 191-215; Jour. Wash. Acad. Sci., vol. 6, June 19, 1916, pp. 400-401, abstract. Results of an investigation to determine the most probable places for finding oil. Studies in detail the stratigraphy and structure. Reviews known productive fields nearby and states conditions in the Cuyama Valley.
150. MARTIN, BRUCE. The Pliocene of middle and northern California. California Univ. Dept. of Geology, Bull., vol. 9, Feb. 29, 1916, pp. 215-219. Includes description of the Merced and the Etchegoin of the Sargent oil field.
151. PACK, R. W. Structural features of the San Joaquin Valley oil fields, California. Jour. Wash. Acad. Sci., vol. 6, May 19, 1916, pp. 309-310, abstract. Enumerates features governing occurrence of oil and shows how they are present in productive fields on the west side of the San Joaquin Valley. Discusses sealing of sandy beds by tar, thus preventing escape of the oil.
152. SMITH, J. P. The geologic formations of California, with reconnaissance geologic map. Bull. 72, California State Min. Bureau, 1916, 41 pp. A report of progress in geologic study of California during the past 25 years, summarized in map form. Discusses the geologic record of California and the rock-forming agencies, and gives tables and a detailed description of the various geologic formations and geologic map.
- See also* Nos. 315, 331.

DEVELOPMENT AND PRODUCTION.

153. ALLISON, L. R. W. Electric operation of oil properties. Elec. World, vol. 67, Jan. 29, 1916, p. 261. Gives short account of the use of electricity in the Kern River oil fields, California, for pumping from a central power station.
154. COX, THOMAS. Methods and costs of producing crude petroleum in California. West. Eng., vol. 7, September, 1916, pp. 347-353. Tables and charts show costs of production, using different methods of pumping.
155. LOMBARDI, M. E. The cost of maintaining production in California oil fields. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 218-223; discussion, pp. 223-224. Gives cost factors in drilling new wells; also, cost per barrel of daily production.
156. McLAUGHLIN, R. P. Protecting California oil fields from damage by infiltrating water. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 225-231; discussion, pp. 231-238. Discusses the character of California sands and the necessity for special care in water exclusion. Describes methods of protection and gives sketch of bottoms of four wells, illustrating methods. Outlines laws regulating repairs of wells.
157. ———. Protecting oil fields from infiltrating water. California Derrick, vol. 9, February, 1916, pp. 3-5. Gives examples of financial loss caused by infiltrating water. Sketches of the bottoms of four wells show underground conditions in the Coalinga field. Explains purpose of State legislation of 1915 regulating oil and gas development.
158. WESTERN ENGINEERING. Natural gas from artesian wells in California. Vol. 7, Feb., 1916, p. 65. Gives description of wells in the vicinity of Stockton, Cal.
- See also* Nos. 415, 416, 478.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

159. ALLISON, L. R. W. Gas-burning furnaces for oil wells. Gas Age, vol. 87, Apr. 1, 1916, p. 412. Describes a furnace in the California oil fields;

gas obtained from the oil wells; furnace is used for heating the oil so that it may be readily handled on its way to storage reservoir.

160. BOWIE, C. P. Oil pipe-line systems in California. *West. Eng.*, vol. 7, Apr., 1916, pp. 153-155. Gives history of development of pipe lines in the State, and construction and operating details of lines in use.
161. COLE, E. D. Concrete-lined oil-storage reservoirs in California. *Trans. Am. Soc. Civ. Eng.*, vol. 80, 1916, pp. 691-714; discussion, pp. 715-722. Describes the construction of these reservoirs in the California oil fields and the methods used to obtain safe and economical results. Also gives the total cost of storage per barrel of capacity.
162. ROALFE, G. D. Storing and measuring oil from a California gusher. *Eng. News*, vol. 76, Dec. 7, 1916, pp. 1066-1068. Describes how old reservoirs were put to use for storing oil from a gusher and how the oil was measured in order to settle rentals.
- See also* No. 549, 614.

PROPERTIES AND THEIR DETERMINATION.

163. OIL AGE. Los Angeles city specifications for oils. Vol. 12, Aug., 1916, p. 32. Gives requirements for gasoline and benzine, also, engine, stove, and furnace distillates.
- See also* No. 478.

REFINING AND REFINERIES.

164. CALIFORNIA OIL WORLD. Refineries in southern California. Sept. 16, 1916, p. 8. Gives list of refineries, their location and daily capacity, and notes special products made by each.
- 164a. BELL, A. F. L. Important topping plants in California. *Trans. Am. Inst. Min. Eng.*, vol. 52, 1916, pp. 185-216; discussion, pp. 216-217. Gives detailed account of plants, with illustrations, and statistical data.

UTILIZATION.

- 164b. ADAMS, W. H. The Diesel engine and its application in southern California. *Trans. Am. Soc. Min. Eng.*, 1915, pp. 447-466; discussion, pp. 466-476. Discusses design, operation, fuels, and costs.
- See also* Nos. 176, 917.

STATISTICS.

DIRECTORIES.

165. Oil, Bradstreet and Mining Directory. Los Angeles, vol. 7, 1916. Gives data on oil companies of California.

FIELD DEVELOPMENT AND PRODUCTION.

166. California State Mining Bureau. Annual report of the mineral production of the State gives production of asphalt, natural gas and petroleum. Annual report of the State oil and gas supervisor gives daily and monthly production of petroleum.
167. California State Mining Bureau. Weekly press bulletins give detailed reports of drilling operations in the State. Annual Reports of the State oil and gas supervisor give details of development. Annual Report of the mineral production of the State gives well operations, by fields and by months.
168. Oil Age. Monthly statement, by fields, with daily average production.
169. Standard Oil Bulletin. Table showing the total production of crude oil in California from the beginning of the industry to 1916, by fields. Vol. 4, June, 1916, p. 12. Total production 851,260,420 bbls.
- See also* Nos. 12-19, 21-34, 154, 164.

GENERAL INFORMATION.

170. California Derrick. Importance of California's oil industry. Vol. 9, Jan., 1916, pp. 3-4. Statistical summary of conditions in California. Gives acreage, wells, daily average production and shipment, surplus at end of 1914; also total investment, value of oil, cost of equipment and operating, etc. Compares petroleum production with other industries of the State.
171. California State Mining Bureau. Report XIV of the State Mineralogist; mines and mineral resources of portions of California; chapters of the State Mineralogist's report, biennial period 1913-1914. Sacramento, 1916, 974 pp. Contains statistics and general information in regard to oil and gas in several counties.

LIST OF NEW INCORPORATIONS.

172. Oil Age. Monthly statement shows new companies.

PRICES.

173. Oil Age. Monthly statement gives prices of all grades of crude oil, by fields; also gives monthly statement of prices in Los Angeles of refined products of petroleum.
174. Oil Trade Journal. Monthly statement gives prices, by fields.

GENERAL REVIEW OF THE INDUSTRY.

175. BERKLEY, J. M. Natural gas development in southern California. Gas Age, vol. 37, May 15, 1916, pp. 573-577. Reviews gas developments and future possibilities on the Pacific Coast.
176. HAMILTON, W. R. The California gasoline industry. Am. Inst. Min. Eng., Bull. 114, June, 1916, pp. 1073-1077. Reviews the gasoline industry, and briefly discusses outlook for increased production. Discusses the Rittman, Burton, Snelling, McAfee, and other cracking processes.
- UTILIZATION, *see* Nos. 962, 995, 1307, 1318; Legal regulations, *see* Nos. 96, 157, 962; Maps, *see* No. 152.

WASHINGTON.

GEOLOGY AND ORIGIN.

177. WEAVER, C. E. The possible occurrence of oil and gas fields in Washington. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 239-247; discussion, pp. 247-249. Concludes that prospects for occurrences of petroleum are unfavorable owing to geologic conditions.
- 177a. ———. Post-Eocene formations of western Washington. Proc. California Acad. Sci., 4th ser., vol. 6, May 6, 1916, pp. 19-40. Geological and faunal studies.
178. ———. The Tertiary formations of western Washington. Washington Geol. Survey Bull. 13, 1916, 327 pp. Describes possible occurrences of petroleum in this part of the State, also, the formations and geologic conditions in various sections. Records drilling operations already carried on.

OTHER FIELDS.

GEOLOGY AND ORIGIN.

179. CHIDSEY, C. E. Do magnetic disturbances indicate oil in Florida, Alabama and Mississippi? Manufac. Rec., vol. 60, March 23, 1916, p. 48. Discusses the relation between the behavior of the compass needle and the distribution of petroleum deposits. Deductions are made concerning the possible oil fields of Florida, southern Alabama, and Mississippi.

180. ——— Possibilities of finding oil in the southeastern Gulf Coast section. *Manufac. Rec.*, vol. 70, Dec. 28, 1916, p. 48. Discusses the relation of magnetic disturbances to oil occurrences.
181. HOPKINS, O. B. Structure of the Vicksburg-Jackson area, Mississippi, with special reference to oil and gas. *Bull. 641-D, U. S. Geol. Survey*, 1916, 28 pp. Gives a geological review of the area, and the possibilities of oil and gas. Suggestions are made relative to prospecting and drilling.

GENERAL REVIEW.

182. NORTHROP, J. D. Petroleum and natural gas in the South as chemical resources. *Manufac. Rec.*, vol. 70, Sept., 1916, pp. 89-91. Reviews the progress of petroleum and natural gas industries in the South and gives results of chemical research in these lines.

ALASKA.

OCCURRENCE.

- 182a. BROOKS, A. H. The petroleum fields of Alaska. *Trans. Am. Inst. Min. Eng.*, vol. 51, 1916, pp. 611-619. Describes progress in various fields and character of oil.

STATISTICS.

IMPORTS.

183. United States Bureau of Foreign and Domestic Commerce. Monthly summary of foreign commerce of the United States. Shows quantity and value of crude and refined oils shipped from the United States to Alaska, by kinds of oil.

TENNESSEE.

GEOLOGY AND ORIGIN.

184. BUTTS, CHARLES. Structure of the southern part of Cumberland County, Tennessee, in relation to the possible occurrence of oil and gas. *Resources of Tenn.*, vol. 6, Apr., 1916, pp. 107-110. Concludes that indications of the occurrence of oil and gas are distinctly unfavorable.
185. PURDUE, A. H. Oil and gas conditions in the Central Basin of Tennessee. *Resources of Tenn.*, vol. 6, Jan., 1916, pp. 3-16. Discusses the conditions necessary for an accumulation of oil and gas. The geologic structure of the Central Basin is described. Concludes that oil can not be found in large amounts, and gas only in quantities for private use.
186. ——— Oil and gas in the Reelfoot Lake district of Tennessee. *Resources of Tenn.*, vol. 6, Jan., 1916, pp. 17-36. The main facts of the geology of the Gulf States are reviewed, and the structure of the Reelfoot district is given. Concludes that conditions are favorable for finding oil in paying quantities, and makes suggestions for future prospecting.

CANADA.

OCCURRENCE.

187. OIL AND GAS JOURNAL. Oil shales in Canada. Vol. 14, Apr. 27, 1916, p. 22. Gives geographical occurrence and history of development of oil shale industry in New Brunswick, Nova Scotia, and Quebec.

188. **PETROLEUM REVIEW.** The possibilities of oil and gas in Nova Scotia. Vol. 35, Sept. 30, 1916, pp. 267-269. Gives localities where there are favorable formations for oil and gas; also gives geologic occurrence, characteristics, and analyses of shales.
189. **SIMPSON, LOUIS.** Oil-bearing shales. Bull. Canadian Min. Inst., Oct., 1916, pp. 868-873. Considers the shale resources of Canada and problems connected with the economical mining and working of the shale.
190. **STANSFIELD, JOHN.** The Petrolia oil field, Ontario. Trans. Canadian Min. Inst., vol. 19, 1916, pp. 371-398. Gives location of the field, the history of its development and its geology. Describes drilling, producing, and storing methods used and the characteristics of the oil.
191. **WRIGHT, W. J.** Moncton map area, New Brunswick. Canada, Geol. Survey Summ. Rept. for 1915. 1916, pp. 179-185. Describes occurrences of oil, gas and shale.
- See also* Nos. 4, 262.

GEOLOGY AND ORIGIN.

192. **BOSWORTH, T. O.** The gas fields of Alberta. Petroleum World, vol. 13, April, 1916, pp. 163-167. Gives geologic occurrence, recent developments, and facts about numerous wells in the following regions: the Sweetgrass anticline of southeastern Alberta; the Battle River anticline of eastern Alberta; the foothill region of southwestern Alberta; and the Athabaska monocline of northern Alberta.
193. **CUNNINGHAM-CRAIG, E. H.** The lessons of the Calgary field. Petroleum World, vol. 13, April, 1916, p. 168. Discusses the folly of booming this field, which has not been thoroughly prospected. Attributes failures to a geologic cause, namely, the lack of sufficiently thick and porous reservoir rocks.
- 193a. **DOWLING, D. B.** Correlation and geological structure of the Alberta oil fields. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 353-362. Detailed descriptions of geology, with map.
194. **FOERSTE, A. F.** Upper Ordovician formations in Ontario and Quebec. Memoir 83, Canada, Geol. Survey, 1916, 279 pp. Studies extent to which it is possible to discover the elements of the Lorraine faunas of New York and of the Cincinnati faunas of Ohio, Indiana and Kentucky in the Upper Ordovician of Ontario and Quebec.
- 194a. **HUNTLEY, L. G.** Oil, gas and water content of Dakota sandstone in Canada and United States. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 329-349; discussion, pp. 350-352.
195. **KINDLE, E. M.** The Ordovician limestones of the Kingston area. Ann. Rept., Ontario Bureau of Mines, vol. 25, 1916, pt. 3, pp. 37-44. Discusses general stratigraphic relations in this area and gives table of Ordovician stratigraphy. Reviews contributions of earlier writers to the subdivision and nomenclature of the Paleozoic rocks of the district.
196. **MAC KENZIE, J. D.** Geology of a portion of the Flathead coal area, British Columbia. Memoir 87, Canada, Geol. Survey, 1916, 49 pp. Describes impregnations of yellowish, brownish and black materials thought to be residues from the evaporation of petroleum. States that some indications of oil are present and some prospecting has been done, but that the chances for commercial deposits are slight.
197. — Geology of Graham Island, British Columbia. Memoir 88, Canada, Geol. Survey, 1916, 207 pp. Discusses the origin and accumulation of petroleum deposits of commercial value. Discusses, also, the oil-shale possibilities of the region.
198. **MCLEARN, F. H.** Jurassic and Cretaceous, Crowsnest Pass, Alberta. Canada, Geol. Survey Summ. Rept. for 1915. 1916, pp. 110-112.

199. MALCOLM, WYATT. Bibliography of Canadian geology for 1914. Trans. Roy. Soc. Canada, 3rd ser., vol. 9, sec. 4, 1915. 1916, pp. 279-305. References arranged by authors.
200. SINCLAIR, J. H. Cretaceous of Alberta, Canada. Bull. Geol. Soc. Am., vol. 27, December, 1916, pp. 673-684; abstract, March, 1916, pp. 85-86. Describes formations, identification of fossils, etc., in the foothills of southern Alberta.
201. SLIPPER, S. E. Boring operations in southern Alberta. Canada, Geol. Survey Summ. Rept. for 1915. 1916, pp. 116-120. Reviews year's work in boring for petroleum and the results obtained. Gives stratigraphy of the Cretaceous in the foothills area based on data obtained from the wells, and notes on the structural geology and the location of wells.
202. WILLIAMS, M. Y. Guelph formation of Ontario. Bull. Geol. Soc. Am., vol. 27, Mar. 81, 1916, pp. 148-149, abstract. Describes this formation which is argillaceous and commonly bituminous.
- See also* Nos. 190, 313, 1342.

DEVELOPMENT AND PRODUCTION.

203. BOYLE, R. W., AND TOBY, H. M. A physical test on a natural (methane) gas well. Trans. Roy. Soc. Canada, 3rd ser., vol. 9, sec. 3, 1915, 1916, pp. 139-145. Gives details concerning discovery of gas at Viking, Alberta, an analysis of the gas found, and tables and curves showing daily rates of flow, taken with a Pitot tube, and maximum pressures.
- See also* Nos. 189, 190.

PROPERTIES AND THEIR DETERMINATION.

204. ASHWORTH, JAMES. The composition of natural gas. Coal Age, vol. 10, July 22, 1916, pp. 146-147. Refutes the criticism of the Clapp report on oil and gas in Canada, as to gas analyses. (*See also* Canadian Min. Jour., vol. 37, Feb. 15, 1916, pp. 86-87; Apr. 1, pp. 157-158, 159.)
205. ELLS, S. C. Investigation of bituminous sands of northern Alberta. Canada Department of Mines, Mines Branch, Summ. Rept. for 1915. 1916, pp. 67-76. Canadian Min. Jour., vol. 37, Feb. 1, 1916, pp. 73-74, abstract. Reviews work of mapping of the bituminous sand region, and gives results of investigation of the sands as a possible paving material. Conclusion is that Alberta bituminous sand can be successfully adopted as a basis for asphaltic surfaces.
206. KEELE, J. Oil shales at Albert Mines and Baltimore. Canada Department of Mines, Mines Branch, Summ. Rept. for 1915. 1916, p. 137. Gives results of experiments to determine the usefulness of oil shales, after the oil is extracted, for the clay working industry. Concludes that if mixed with a plastic clay its qualities are improved, but not sufficiently to warrant its use.
- See also* Nos. 190, 203, 257.

STATISTICS.

FIELD DEVELOPMENT AND PRODUCTION.

207. Canada, Geol. Survey. Memoirs. Canada Department of Mines, Mines Branch. Annual report on the mineral production of Canada; Bulletins.
208. Great Britain, Mines and Quarries. General report, with statistics (annual), by chief inspector of mines; pt. 4, Colonial and foreign statistics.

209. HORE, R. E. Canadian mining manual. Toronto, 1916-17, p. 151. Describes oil fields and gives annual figures of production.
210. HEATON, E., ROBINSON, J. B., and DOBSON, W. J. Heaton's annual; the commercial handbook of Canada. Toronto, 1916, 530 pp. Contains material on mining and an economic bibliography of all government reports.
- PRICES.
211. Oil and Gas Journal. Weekly report. Prices of Canadian oil listed under "Eastern States."
212. Oil Trade Journal. Monthly report of price of Petrolia oil.
213. Petroleum. Monthly report of price of Canadian oil.
- STORAGE, *see* No. 190; Refining and refineries, *see* No. 189; Utilization, *see* Nos. 205, 206.

MEXICO.

OCCURRENCE.

214. CRUZ, S. C. Estudio del campamento de Tecuanapa (a study of the region of Tecuanapa). Bol. del Petróleo, vol. 2, November, 1916, pp. 423-446. Describes character, history, exploration, and exploitation of the field; gives cost of drilling, production statistics, and properties and value of the oil.
- 214a. DE GOLYER, E. The Furbero oil field, Mexico. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 268-280. Gives location, history and development, and geology of the field. See also Bull. Am. Inst. Min. Eng., Sept., 1915, pp. 1899-1911. (No. 191, 1915 Bibliography.)
- 214b. DUMBLE, E. T. The occurrences of petroleum in eastern Mexico as contrasted with those in Texas and Louisiana. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 250-265; discussion, pp. 265-267. See also Bull. Am. Inst. Min. Eng., Aug., 1915, pp. 1623-1638; Discussion, December, 1915, pp. 2434-2435. (No. 192, 1915 Bibliography.)
215. ESPINOSA, E. M. Petróleo en Chiapas (Petroleum in Chiapas). Bol. del Petróleo, vol. 2, July, 1916, pp. 22-23. Gives localities in which "chapoté" is found in this region.
216. LAVÍN, J. D. Introducción a la explotación del petróleo Mexicano (Introduction to the development of Mexican petroleum). Bol. del petróleo, vol. 2, October, 1916, pp. 307-367. Gives a detailed account of the Mexican industry. Discusses drilling, producing, and transportation methods.
217. VILLARELLO, J. D. Apuntes sobre la region petrolifera Tabasco-Chiapas (Notes on the petroleum region of Tabasco-Chiapas). Bol. del petróleo, vol. 2, July, 1916, pp. 10-17. Discusses the transportation facilities, topography, and geology of the region and the surface indications of oil.
- See also* Nos. 3, 4.

GEOLOGY AND ORIGIN.

218. ORDÓÑEZ, EZEQUIEL. Ligero apunte sobre los campos petroliferos de México (Information on the petroleum fields of Mexico). Bol. del petróleo, vol. 2, August, 1916, pp. 96-99. Article shows that the connection between petroleum and volcanic formations has nothing to do with the origin of petroleum, which the author believes to be purely organic.
219. WHITE, I. C. Geological features of the Cerro Azul well in Mexico. Pan American Rec., vol. 1, November, 1916, pp. 7-10. Address delivered at National Exposition of Chemical Industries, Sept. 26, 1916. Reviews the history of the well and the geologic conditions accompanying it.
- See also* No. 217.

DEVELOPMENT AND PRODUCTION.

- 220.** BAZ, JULIO. Accidentes en los grandes pozos de petróleo (Accidents at large petroleum wells). Bol. del petróleo, vol. 1, February, 1916, pp. 132-140. Describes methods of extinguishing oil fires in Mexico.
- 221.** FASBINDER, A. G. A fire that burned four months. Pop. Sci. Monthly, vol. 88, January, 1916, pp. 3-6. Describes the burning and extinguishing of the fire at Potrero del Llano No. 4, near Tampico, Mexico.
- 222.** MEXPET RECORD. Cerro Azul No. 4, world's greatest oil well. Vol. 1, March, 1916, pp. 10-16. Describes discovery of this well on Feb. 10, 1916. See also Nos. 214, 216, 217, 219.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

- 223.** BAZ, CARLOS. Bases que se proponen para la formación de tablas y reglamentos oficiales para la medición del petróleo (Basis considered for the formation of tables and official rules for measuring petroleum). Bol. del Petróleo, vol. 2, July, 1916, pp. 17-22. Gives rules and formulas for the official and uniform measurement of petroleum in Mexico.
- 224.** LANGARICA, ALBERTO. Desperdicio de los recursos naturales (Waste of natural resources). Bol. del Petróleo, vol. 2, November, 1916, pp. 415-422. Discusses causes of waste of petroleum and natural gas, particularly evaporation while in storage, and natural-gas gasoline manufacture as a means of conserving gas. Concludes that government regulation is the only efficient means of checking losses and suggests a prescribed percentage of evaporation tolerance and method of determining it.
- 225.** ———. A propósito del almacenamiento de petróleo (On the method of storing petroleum). Bol. del Petróleo, vol. 2, August, 1916, pp. 100-108. Discusses storage of oil in wooden, concrete, earthen, and steel tanks in Mexico. Also construction of the tanks and fire hazards.
- 226.** STEWART, P. C. A. Submarine pipe-lines for loading tank steamers at Tuxpam, Mexico. West. Eng., vol. 7, January, 1916, p. 9. Extract from paper before the Inst. Petroleum Technologists, London. Describes methods of loading oil where ocean-going ships can not come near shore.
- 227.** VÁZQUEZ, LEOPOLDO. De la medición y calculo del petróleo (Measurement and calculation of petroleum). Bol. del Petróleo, vol. 1, January, 1916, pp. 26-31. Discusses measurement of volumes in storage, sampling, testing for specific gravity, etc.

See also Nos. 214, 216, 217, 583, 586.

PROPERTIES AND THEIR DETERMINATION, see No. 214.

STATISTICS.

EXPORTS.

- 228.** Oil Trade Journal. Monthly statement of shipments of oil from Tampico and Tuxpam into the United States, by points of destination.

IMPORTS.

- 229.** United States Geological Survey. Mineral Resources, pt. 2, Nonmetals. Gives annual statistics of petroleum and petroleum products imported into Mexico from the United States.

PRODUCTION OF PETROLEUM, NATURAL GAS AND ASPHALT.

- 229a.** HUNTLEY, L. G. The Mexican oil fields. Trans. Am. Inst. Min. Eng., vol. 52, 1916, pp. 281-321. Gives production 1904 to 1914 and list of companies operating.
- 230.** United States Geological Survey. Mineral resources, pt. 2, Nonmetals. Gives figures of annual production.

WEST INDIES.

GEOGRAPHIC OCCURRENCE, *see* Nos. 3, 4,

STATISTICS.

- 231. UNITED STATES GEOLOGICAL SURVEY.** Mineral resources, pt. 2, Nonmetals. Gives annual production of petroleum and asphalt in the West Indies.

BARBADOS.

STATISTICS, *see* Nos. 16, 231.

CUBA.**PROPERTIES AND THEIR DETERIORATION.**

- 232. ORTEGA, PABLO.** Review of the present state of mining in Cuba. Boletín de Minas, Habana, Cuba, I, 1916, 157 pp. Gives a statistical review containing some analyses of Cuban petroleum.
- STATISTICS,** *see* Nos. 16, 231, 232.

TRINIDAD.**GEOLOGY AND ORIGIN.**

- 233. NATIONAL PETROLEUM NEWS.** Development of Trinidad oil territory. Vol. 8, July, 1916, p. 92. Gives a short review of conditions in Trinidad and discusses opening of a fuel-oil market for the navies of the world. Gives distillation test of Trinidad oil, its geologic occurrence, developing companies, and the uses to which the oil is being put.
- 234. WILLOCK, G. S. O.** Description of Trinidad's oil fields. Fuel Oil Jour., vol. 7, Jan., 1916, p. 49. Brief description of properties of oil and its occurrence.

PROPERTIES AND THEIR DETERMINATION.

- 235. MILLER, J. S.** Colloids and their occurrence in Trinidad Lake asphalt. Jour. Eng. Club, Baltimore, vol. 6, Dec., 1916, pp. 131-136. Reviews progress in the study of colloids, the discovery of finely divided clay in Trinidad asphalt. Describes manner of occurrence in the asphalt.
- See also* Nos. 16, 233, 234.
- UTILIZATION,** *see* No. 233; **Statistics,** *see* No. 231.

PORTO RICO.**STATISTICS.**

- 236. UNITED STATES BUREAU OF FOREIGN AND DOMESTIC COMMERCE.** Monthly summary of foreign commerce of the United States. Gives quantity and value of crude and refined mineral oil shipped to Porto Rico.

SOUTH AMERICA.

GEOGRAPHIC OCCURRENCE, *see* Nos. 3, 4.

GEOLOGY AND ORIGIN.

- 237. BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.** Nomenclature of the carboniferous, permo-carboniferous, and permian rocks of the southern hemisphere. Report of the 85th meeting, Manchester, 1915. 1916, pp. 263-282. Report of the Australian members of the committee giving tables of suggested correlation of these rocks, and presenting points for discussion. Tables include New South Wales, Victoria, Queensland, West Australia, South Australia, Tasmania, New Zealand, South Africa, South America, and India.

STATISTICS.

PRODUCTION.

- 238. UNITED STATES GEOLOGICAL SURVEY.** Mineral resources, pt. 2, Nonmetals. Gives annual production figures for principal producing countries.

ARGENTINA.

OCCURRENCE.

- 239. HERMITTE, E. M.** Area, distribution and present working of petroleum deposits in Argentina. Jour. Ind. and Eng. Chem., vol. 8, February, 1916, pp. 194-195. Abstract of paper presented before the Pan-American Scientific Congress, 1915. Gives location and character of deposits, production figures for 1914 and 1915, and quality of oil.
- 240. PETROLEUM AGE.** Latin-American oil developments. Vol. 3, July, 1916, pp. 7-10; September, 1916, pp. 12-14. Reviews developments in Latin-American countries: Argentina, Colombia, Brazil, Peru, Ecuador, Bolivia, Costa Rica, Chile.
- 241. WINDHAUSEN, ANSELMO.** Los yacimientos petroliferos de la zona Andina (The petroleum deposits of the Andina zone). Argentine Republic, Dirección General de Minas, Geología e Hidrología, Bol. 15, ser. B, 1916, 27 pp. Includes provinces of Mendoza and Neuquen.

PROPERTIES AND THEIR DETERMINATION.

- 242. CORTI, HÉRCULES.** Determinación del porcentaje de agua en el petróleo de Comodoro Rivadavia (Determination of the percentage of water in the petroleum of Comodoro Rivadavia). Argentine Republic, Dirección General de Minas, Geología e Hidrología, Bol. 3, ser. D, 1916, pp. 5-11. Discusses determination of water in suspension in viscous petroleum, by adding a light gasoline to the petroleum and allowing the water to separate.
- 243. DANKERT, E. G.** Algunos ensayos y consideraciones sobre el coke del petróleo de Comodoro Rivadavia (Some experiments and considerations in regard to the coke of the petroleum of Comodoro Rivadavia). Argentine

República, Dirección General de Minas, Geología e Hidrología, Bol. 3, ser. D, 1916, pp. 12-15.

See also No. 239.

STATISTICS, *see* Nos. 238, 239.

PERU.

OCCURRENCE.

244. BLARDONE, GEORGE. High-grade oil is produced in Peru. Oil and Gas Jour., vol. 14, Mar. 9, 1916, p. 30. Short review of developments in Lobitos and other fields of Peru. Oil obtained tests above 30° B. and output for 1914 was nearly 2,000,000 bbls.

245. DEUSTUA, R. A. La industria del petróleo en el Perú durante 1915 (The petroleum industry in Peru during 1915). Inf. y Mem. Soc. Ing. Peru, vol. 18, Apr.-June, 1916, pp. 117-149. Paper presented at Second Pan-American Scientific Congress, 1915. Gives history of the industry, location and description of the petroleum deposits, and statistics of production, exploitation, imports and exports.

246. SINGEWALD, J. T., Jr. Mining industry of Peru. Eng. and Min. Jour., vol. 101, May 13, 1916, pp. 845-850. Briefly discusses the oil industry and its prospects.

See also No. 240.

PROPERTIES, *see* No. 244.

STATISTICS.

FIELD DEVELOPMENT AND PRODUCTION.

247. Peru, Cuerpo de Ingenieros de Minas. Boletín. Contain statistics of oil production, drilling, etc.

See also No. 245.

OTHER COUNTRIES.

OCCURRENCE, STORAGE, AND TRANSPORTATION, ETC.

248. MARSTRANDER, ROLF. The mineral resources of Uruguay. Mining Mag., vol. 14, June, 1916, pp. 315-320. Occurrence and composition of shales are given. Little is yet known of the oil possibilities.

249. PETROLEUM REVIEW. The oil regions of Ecuador. Vol. 34, March 4, 1916, p. 193. Describes geography of the region and discusses its natural facilities for transportation of oil, the lack of capital for oil exploitation, the oil indications, and the commercial facilities.

250. UNITED STATES DEPARTMENT OF COMMERCE. Ecuador developing oil industry. Daily consular and trade reports, No. 165, July 15, 1916, pp. 186-188. Gives location of deposits, cost of drilling, analysis of oil, and statistics of imports for years 1911 to 1915.

See also No. 240.

VENEZUELA.

STATISTICS.

EXPORTS.

251. UNITED STATES GEOLOGICAL SURVEY. Mineral resources, pt. 2, Non-metals. Annual statistics of asphalt.

EUROPE.

OCCURRENCE.

- 252. PETROLEUM ZEITSCHRIFT.** Zur Lage der europäischen Schieferölindustrie mit besonderer Berücksichtigung Luxemburgs. Jahrg. 11, Sept. 20, 1916, pp. 1308-1315. Gives account of shale-oil industry in the Duchy of Luxemburg, Scotland, France, Sweden, and Germany, the extent of the development of oil-shale resources, the occurrence and composition of the shales, and the characteristics of distillation products.

TRANSPORTATION, STORAGE, AND DISTRIBUTION.

- 253. WALMSLEY J.** The Danube and the petroleum industry. Petroleum World, vol. 13, May, 1916, pp. 227-229. Describes how petroleum can be transported from Russia and Roumania to the heart of Germany.

PROPERTIES, see Nos. 252, 257.

STATISTICS.

PRODUCTION.

- 254. UNITED STATES GEOLOGICAL SURVEY.** Mineral resources, pt. 2, Non-metals. Annual statistics for principal producing countries.

AUSTRIA-HUNGARY.

HISTORICAL REFERENCES AND GEOGRAPHIC OCCURRENCE.

- 255. ARNDT, R.** The natural gas industry of Hungary. Petroleum World, vol. 13, August, 1916, p. 367, abstract. Discusses discovery of natural gas at Kissarmas in 1909, borings and development, compression and transportation facilities, industrial and other uses.
- 256. PETROLEUM ZEITSCHRIFT.** Zur Geschichte und Oertlichkeit der Siebenbürgischen Erdgasfelder (On the history and location of the Transylvania gas fields). Jahrg. 11, Feb. 2, 1916, pp. 444-452.
- 257. POIS, ANTON.** Das Erdgas und seine Erschliessung und wirtschaftliche Bedeutung (Natural gas, its development and commercial importance). Petroleum Ztschr., Jahrg. 11, July 19, 1916, pp. 1045-1053; Aug. 2, 1916, pp. 1101-1108; Aug. 16, 1916, pp. 1165-1174; Sept. 6, 1916, pp. 1232-1237. Considers especially the Hungarian fields, reviews the occurrence of natural gas in the principal producing countries and discusses its origin and geologic occurrence. Gives table of analyses of gas from the United States, Canada, and European countries and discusses physical and chemical characteristics. Discusses, also, drilling methods and machinery.

See also Nos. 3, 129.

GEOLOGY AND ORIGIN.

- 258. NOWAK, JAN.** Ueber die tektonischen Bedingungen des Erdöl-vorkommens in den polnischen Ostkarpathen (on the structural conditions of oil

occurrences in the Polish East Carpathian). *Petroleum Ztschr.*, Jahrg. 11, June 21, 1916, pp. 925-927; discussion, Jahrg. 11, Sept. 6, 1916, p. 1231. Discusses the relation between geologic structure and the occurrence of oil, the structure of this field, and oil prospects.

See also Nos. 129, 257.

DEVELOPMENT AND PRODUCTION.

259. MILLAR, ARTHUR. The raising of oil on the Boryslaw-Tustanowice oil fields of Galicia. *Petroleum World*, vol. 3, December, 1916, pp. 568-570. Describes method of swabbing deep wells and the construction of the plunger, winch, etc., used.

See also No. 129.

PROPERTIES AND THEIR DETERMINATION, *see* Nos. 131, 257; Refining and refineries, *see* No. 129; Transportation and storage and utilization, *see* No. 255; Statistics, *see* No. 254.

GERMANY.

HISTORY, GEOGRAPHIC OCCURRENCE, AND PROPERTIES, *see* No. 257; Utilization, *see* Nos. 1261, 1263.

GREAT BRITAIN.

OCCURRENCE.

260. FORBES-LESLIE, WILLIAM. The Norfolk oil-shales. *Jour. Inst. Petroleum Tech.*, vol. 3, December, 1916, pp. 3-26; discussion, pp. 27-35. Gives history and geologic and geographic occurrence of oil shales of England. The Wormegay shales of Norfolk are described in detail.
261. MANFIELD, W. H. Oil shales, with especial reference to those of the Dorsetshire Kimmeridgian series. *Jour. Inst. Petroleum Tech.*, vol. 2, April, 1916, pp. 162-182; discussion, pp. 182-190; bibliography, pp. 178-182, by W. H. Dalton. Reviews the geologic and geographic distribution of oil shales in the world and the origin and development of the British oil shale industry. Kimmeridge shales are described in detail and methods are given for proving, mining, treating, and utilizing them.
262. SELWYN-BROWN, ARTHUR. Fuel oil from shale. *Eng. Mag.*, vol. 50, March, 1916, pp. 913-920. Describes classes of shales and their mining and distillation. Discusses geology and origin of oil shales. Gives analyses of English, Welsh, and Scotch coals and shales. Properties and composition of albertite, tasmanite, and torbanite are included.
263. STEUART, D. R. Shale oil industry. *Jour. Soc. Chem. Ind.*, vol. 35, July 31, 1916, pp. 774-776. Gives occurrence, geographic and geologic, of the shale measures of Scotland. Describes distillation, refining, and use of shale products—crude oil, ammoniacal liquor, permanent gas, and spent shale.

See also No. 252.

GEOLOGY AND ORIGIN.

264. CONACHER, H. R. J. Oil shales and torbanites. *Trans. Geol. Soc. Glasgow*, vol. 16, part 2, pp. 164-192; *Petroleum Rev.*, vol. 35, Dec. 23, 1916, p. 509. Gives results of a microscopic study of the shales and torbanites of the Lothians to ascertain the substances in them that yield on distillation olefins, paraffins, and naphthenes in large proportions, whereas coal under similar treatment yields only tar containing small proportions of these compounds. Describes experiments and concludes that oil shales

and torbanites are derived from the same substances as coal—vegetable matter—but that in the shales there has been a much more complete elimination of the woody matter, leaving the resins, cellulose and mud.

- 265. CUNNINGHAM-CRAIG, E. H.** Petroleum or natural gas in Scotland. *Petroleum World*, vol. 13, June, 1916, pp. 260-271. Discusses whether or not Scotland possesses oil or gas in commercially important quantities; considers the series of strata, geologic structures, and evidence of the presence of petroleum found in anticlinal areas.

See also Nos. 260-263, 313.

PROPERTIES AND THEIR DETERMINATION.

- 266. BRITISH ENGINEERING STANDARDS COMMITTEE.** British standard nomenclature of tars, pitches, bitumens, and asphalts when used for road purposes, and British standard specifications for tar and pitch for road purposes. Report No. 76, London, April, 1916, 16 pp.; extract in *Good Roads*, vol. 12, new ser., July 1, 1916, p. 81.

See also Nos. 252, 257, 260-262.

STATISTICS.

IMPORTS.

- 267. Great Britain, Mines and Quarries.** General report, with statistics (annual), by Chief Inspector of Mines. Pt. 3, Output. Gives statistics, by countries.

- 268. Petroleum Review.** The petroleum trade of England during 1915. Vol. 34, Jan. 8, 1916, pp. 25-26. Statistics of imports into the United Kingdom, by countries and kinds of products.

- 269. ———** Weekly review classifies imports by countries.

PRODUCTION OF PETROLEUM.

- 270. Great Britain, Mines and Quarries.** General report, with statistics (annual), by Chief Inspector of Mines. Pt. 4, Colonial and foreign statistics. Gives production statistics for all British colonies.

PRODUCTION OF SHALE IN SCOTLAND.

- 271. Great Britain, Mines and Quarries.** General report, with statistics, for 1916 (annual), by Chief Inspector of Mines. Pt. 3, Output. Gives statistics of oil-shale industry in Scotland.

TRANSPORTATION, STORAGE AND DISTRIBUTION, *see* No. 533; Refining, refineries, and utilization, *see* Nos. 261, 262, 263.

ROUMANIA.

GEOGRAPHIC OCCURRENCE AND GEOLOGY.

- 272. HENNION, CHARLES, Jr.** The new Balcol field of Roumania. *Petroleum World*, vol. 13, August, 1916, pp. 375-376. Gives output of the field and describes location, geologic formation and occurrence of oil.

See also No. 3.

DEVELOPMENT AND PRODUCTION.

- 273. PETROLEUM REVIEW.** The new well of the Romano-Americana Company in Roumania. Vol. 35, Aug. 12, 1916, pp. 133-134. Describes precautionary measures taken for capping of well. Discusses use of the Tacit-Puscariu valve and the perfect installation of the capping. A production of 45,000 tons has been obtained from one well without any loss or danger.

PROPERTIES AND THEIR DETERMINATION, *see* No. 747.

STATISTICS.

PRICES.

274. *Petroleum Review*. Home and foreign market intelligence gives weekly report of prices.

PRODUCTION.

275. *Petroleum Review*. Gives monthly production figures.

RUSSIA.

OCCURRENCE.

276. HOLIDAY, F. A. The Uralsk Province and its oil fields. *Jour. Inst. Petroleum Tech.*, vol. 2, February, 1916, pp. 87-117; discussion, pp. 118-122. Describes development of the oil fields, the geology of the region and occurrence of the oil, the refineries, and transportation facilities. Gives a list of places at which oil indications are found and a bibliography on the region. (See also No. 1340.)
277. PETROLEUM AGE. Russia's newly verified oil field. Vol. 3, August, 1916, pp. 13-15. Gives a general description of the region and history of oil developments.
- See also No. 3.

GEOLOGY AND ORIGIN.

278. HUNTLEY, L. G. The Baku oil fields; discussion of a paper by A. Adiasse-vich. *Econ. Geol.*, vol. 11, Apr.-May, 1916, pp. 279-283. Criticism of statements on the Russian oil fields as to the thickness of some of the producing series of oil sands in the Baku district.
279. PETROLEUM REVIEW. The new Apsheron areas; why they will not justify commercial exploitation. Vol. 35, Oct. 14, 1916, p. 306; Oct. 21, 1916, p. 337. Considers rôle of geology in determining profitable deposits. Concludes that most of the areas are not commercially productive.
- See also No. 276.

PROPERTIES, see No. 257.

STATISTICS.

FIELD DEVELOPMENT AND PRODUCTION.

281. *Petroleum Review*. Monthly statement of production and drilling operations in different fields.

PRICES.

282. *Petroleum Review*. Gives weekly report of prices.

TURKEY.

GEOGRAPHIC OCCURRENCE AND GEOLOGY.

283. DEBATIN, OTTO. Die Erdölschätze Mesopotamiens (The petroleum wealth of Mesopotamia). *Petroleum Ztschr.*, Jahrg. 11, May 17, 1916, pp. 818-820; *Petroleum Rev.*, vol. 34, Feb. 12, 1916, pp. 129-130. Gives history and modes of occurrence from Biblical times, and distribution at present time. Discusses lack of transportation facilities and prospects for future development.
284. DOELTER, C. Die Mineralschätze der Türkei (The mineral wealth of Turkey). *Montan. Rundschau*, Jahrg. 8, pp. 217-220; *Chem. Zentr.*, 1916, II, p. 108. Discusses the occurrence of petroleum and asphalt.

- 285.** DOMINIAN, LEON. Fuel in Turkey. Bull. Am. Inst. Min. Eng., June, 1916, pp. 1022-1030. Gives geographic and geologic occurrences of oil and asphalt in Syria, Mesopotamia, and European Turkey and the history of the early use of oil and bitumens in Turkey.
- 286.** FRECH, F. Die Erdölvorkommen an der türkisch-persischen Grenze (The occurrence of petroleum on the Turko-Persian border). Petroleum Ztschr., Jahrg. 11, Feb. 16, 1916, pp. 473-480. Describes the occurrences of petroleum in this region, with statements as to their strategical importance for the Bagdad railroad and for export.
- 287.** ——— Mineral resources of Asia Minor. Jour. Soc. Chem. Ind., vol. 35, Mar. 15, 1916, p. 313. Brief descriptions are given of all mineral deposits, including petroleum.

OTHER COUNTRIES.

GEOLOGY AND ORIGIN.

- 288.** CHOFFAT. Les recherches d'hydrocarbures au Portugal (Hydrocarbon resources in Portugal). Revue Sci., t. 54, Jan. 1-8, 1916, p. 26. Discusses possibilities of petroleum deposits in Portugal.
- GEOGRAPHIC OCCURRENCE,** see No. 252; **Properties,** see Nos. 252, 289.

DEVELOPMENT AND PRODUCTION.

- 289.** PETROLEUM WORLD. Italy's petroleum resources. Vol. 13, June, 1916, p. 275. Discusses possibilities of the Rivanazzano field. Gives well log and character of the oil. States that as a result of drilling, abundant indications of petroleum and gas suitable for use in engines have been found.
- 289a.** Revista del Servizio Minerario gives annual statistics for Italy.

ASIA.

STATISTICS.

PRODUCTION OF PETROLEUM, NATURAL GAS AND ASPHALT.

290. United States Geological Survey. Mineral Resources for 1915, pt. 2, Non-metals. Gives annual statistics for principal producing countries.

CHINA.

OCCURRENCE.

291. WAY, H. W. L. The minerals of Sze-Chuan, China. Mining Mag., vol. 15, July, 1916, pp. 20-23. Includes a description and occurrence of the brine, petroleum, and natural gas wells in the Red Basin. Describes method of obtaining the brine.

DEVELOPMENT AND PRODUCTION.

292. RICHARDSON, H. K. The salt wells of Tzulutsing, China. Sci. Am. Suppl., vol. 82, Nov. 18, 1916, pp. 324-325. Describes the gas wells which are drilled in the same manner as the salt wells. The wells are not capped, but a cement box is built around the top, close under the ground, and serves as a gas collecting chamber.

See also Nos. 291, 338.

INDIA.

OCCURRENCE.

293. NASSE, V. P. H. The oil fields of Burma. Petroleum Rev., vol. 35, Dec. 9, 1916, pp. 473-474. Gives a brief general description of the fields.

See also No. 3.

GEOLOGY AND ORIGIN, *see* No. 237.

STATISTICS.

IMPORTS.

294. India Geological Survey Records. Gives annual statistics.

PRODUCTION OF PETROLEUM.

295. Great Britain. Mines and Quarries. General report, with statistics for 1915 (annual), by chief inspector of mines; pt. 4, Colonial and foreign statistics.

JAPAN.

HISTORICAL REFERENCE.

296. OIL AND GAS JOURNAL. Oil discovery in Japan in the seventh century. Vol. 15, Aug. 24, 1916, p. 32. Quotes from the Japanese Petroleum Times, giving early history of petroleum in Japan.

GEOLOGY AND ORIGIN.

297. KOBAYASHI, GIICHIRO. On the accumulation of oil and gas in the Miyagawa oil field, in the Province of Echigo. Bull. Imperial Géol. Survey of Japan, vol. 25, No. 2, 1916, pp. 41-46. Shows that the accumulation of oil and gas may not be easily explained by the anticlinal theory. Gives a detailed description of the surface and underground geology of the field.

PERSIA.

HISTORY AND GEOGRAPHIC OCCURRENCE, *see* No. 3.

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AFRICA.

GEOLOGY AND ORIGIN.

- 298.** DU TOIT, A. L. Report on the oil-shales of Impendhle county, Natal. South Africa Geol. Survey, 1916, 11 pp; South African Min. Jour., October 28, 1916, pp. 193-194. Gives geological description and map of region and occurrence and character of shale.
- 298a.** HUME, W. F. Report on the oil fields of Egypt, with a geological map of the region from surveys of John Ball.
- See also* Nos. 237, 313.

STATISTICS.

- 299.** UNITED STATES GEOLOGICAL SURVEY. Mineral Resources for 1915, pt. 2, Nonmetals. Annual production figures for Egypt.
- HISTORY AND GEOGRAPHIC OCCURRENCE,** *see* Nos. 3, 262; Properties, *see* No. 298; Maps, *see* No. 298.

OCEANIA AND MALAYSIA.

GEOLOGY AND ORIGIN.

- 300.** ANDREWS, E. C. Notes on the structural relations of Australasia, New Guinea and New Zealand. Jour. Geol., vol. 24, Nov.-Dec., 1916, pp. 751-776. The oil fields of New Guinea suggest the Burmese or Malaysian origin of the New Guinea lines of structure.

STATISTICS.

PRODUCTION OF PETROLEUM AND ASPHALT.

- 301.** United States Geological Survey. Mineral Resources for 1915, pt. 2, Nonmetals. Gives annual statistics of principal producing localities.

AUSTRALIA.

GEOGRAPHIC OCCURRENCE, *see* No. 202.

GEOLOGY AND ORIGIN.

- 302.** CAMERON, W. E. Petroleum prospects at Roma, Queensland. Petroleum Rev., vol. 35, Sept. 23, 1916, pp. 255-256. Gives a historical sketch of inquiries and discussions on the subject.
- 303.** CLARKE, E. DE C. The reported occurrence of oil near Wonnerup, South-West Division. Western Australia Geol. Survey, Ann. Rept. of Progress for the year 1915, 1916, pp. 25-26. Describes indications of oil from the geological evidence as slight and unfavorable. (*See also* No. 304.)
- 304.** SIMPSON, E. S. On samples of supposed petroleum-bearing earths and water from Wonnerup. Western Australia Geol. Survey, Ann. rept. of Progress for the year 1915. 1916, p. 26. Gives results of examination of samples of wet sand, clay, and water from this region and concludes that there are no indications of petroleum residues. (*See also* No. 303.)
- 305.** WADE, ARTHUR. Petroleum prospects of Bruny Island, Tasmania. Tasmania Parliament Report No. 60, 1916, — pp.; Petroleum Rev., vol. 35, Aug. 19, 1916, pp. 153-154; Aug. 20, pp. 175-176. Considers in detail the geology of the northern part of the island, which consists chiefly of diabase rocks which have been intruded into, and which have considerably affected, a series of strata of Permo-Carboniferous age. Concludes that evidence on finding of seepages without complete investigation is insufficient, and that neither the presence of coal beds nor of fossils necessarily indicates the presence of oil.

See also Nos. 237, 313.

DEVELOPMENT AND PRODUCTION.

306. DUNLEAVY, F. L. Drilling for oil in Australia. Oil age, vol. 12, March, 1916, pp. 14-15. Describes attempt to discover oil. Machines capable of drilling to 4,000 feet are being used. Oil claims can not exceed 640 acres in area. Mining laws are liberal.

BORNEO, JAVA, AND SUMATRA.

HISTORY AND GEOGRAPHY OCCURRENCE, *see* No. 3.

NEW GUINEA.

GEOLOGY AND ORIGIN, *see* No. 300.

NEW ZEALAND.

GEOLOGY AND ORIGIN, *see* No. 237.

307. FRASER, MALCOLM. The New Zealand Official Year-Book, 1916. Prepared under the instruction of the Government of New Zealand. Wellington, 1916, p. 491. Briefly reviews petroleum situation in New Zealand and gives analyses of New Zealand oil.

PHILIPPINES.**GEOLOGY, ORIGIN, AND PROPERTIES.**

308. PETROLEUM REVIEW. Oil fields of Tayabas Peninsula, Philippine Islands. Vol. 35, Nov. 4, 1916, pp. 375-376. Gives a geologic study of the region, characteristics of the oil, and a discussion of future prospects.
309. PRATT, W. E. The occurrence of petroleum in the Philippines. Econ. Geol., vol. 11, Apr.-May, 1916, pp. 246-265. Gives geology, stratigraphy, structure, and occurrence of petroleum, by districts. Table shows results of fractional distillation. Character and commercial possibilities of the petroleum are given.

STATISTICS.

310. UNITED STATES BUREAU OF FOREIGN AND DOMESTIC COMMERCE. Monthly summary of foreign commerce of the United States. Gives quantity and value of crude and refined mineral oils exported to the Philippine Islands.

NEW CALEDONIA.**OCCURRENCE.**

311. PETROLEUM WORLD. Oil struck at New Caledonia. Vol. 13, Nov., 1916, p. 538. Gives a short account of finding of oil seepages on this island and predicts further success in drilling.

GEOLOGY AND ORIGIN.

GENERAL GEOLOGY. 210

312. CLAPP, F. G. The geology of petroleum. The American Petroleum Industry, by R. F. Bacon and W. A. Hamor, New York, 1916, pp. 34-68. Reviews the surface indications of petroleum, character and geologic age of oil bearing formations and their stratigraphic and structural relations, the migration of petroleum, and types of structure with which oil pools are associated. Gives a classified arrangement of petroleum accumulations based on geologic structure.
313. CUNNINGHAM-CRAIG, E. H. Kerogen and kerogen shales. Jour. Inst. Petroleum Tech., vol. 2, June, 1916, pp. 238-269; discussion, pp. 270-273. An inquiry into the origin of kerogen and the manner in which it has become associated with argillaceous beds to form kerogen shales. Discusses geologic, microscopic and chemical evidence of the occurrence of kerogen. Short accounts are given of the geological history of the known oil-shale fields of Scotland, South Africa, New South Wales, and Canada.
314. HAGER, DORSEY. Practical oil geology; the application of geology to field problems. New York, 1916, 2nd ed., 187 pp.
315. ROGERS, G. S. Oil field waters and their chemical relations to oil; particularly the conversion of sulphates into carbonates by hydrocarbons. Jour. Wash. Acad. Sci., vol. 6, Apr. 4, 1916, pp. 189-190, Abstract. Gives results of a study of several hundred analyses of water from the San Joaquin Valley oil fields, California. Heaviest oil is that nearest the outcrop and that in zone of "tar sands" above main oil zone.
- See also* Nos. 2, 3, 257.

GEOLOGIC STRUCTURE. 240

316. BELL, H. W. Geometry of dip, strike, and pitch as applied to oil formations. West. Eng., vol. 7, August, 1916, pp. 287-288. Solves problem of geologic structure and shows sketch of well logs.
317. CONKLING, R. A. The influence of the movement in shales on the area of oil production. Bull. Am. Inst. Min. Eng., Nov., 1916, pp. 1968-1972. As a possible aid in making estimates of production and values of oil properties, author describes the thickening of shale in a section of the Cushing pool.
318. HAGER, DORSEY. The occurrence of the older beds in structural depressions. Econ. Geol., vol. 11, Apr.-May, 1916, pp. 276-278. States that in some cases the exposure of older beds surrounded by beds of younger age indicates a structural depression, rather than a doming. Diagram shows condition in Oklahoma and Kansas which proves this theory.
319. NATURAL GAS JOURNAL. What is an anticline? Vol. 10, March, 1916, pp. 100-101. Gives questions and answers relative to anticlines.
- See also* Nos. 142, 312.

ORIGIN—THEORIES. 250

320. CLARKE, F. W. The natural hydrocarbons. Bull. 616, U. S. Geol. Survey, 1916, pp. 713-726. Gives analysis of different oils and theories of origin.

Reviews experiments in laboratory preparation of hydrocarbons from inorganic sources and from more complex organic matter.

321. RICHARDSON, CLIFFORD. Gilsonite and grahamite: the result of the metamorphism of petroleum under a particular environment. *Jour. Ind. and Eng. Chem.*, vol. 8, June, 1916, pp. 493-494. Discusses briefly the effect of environment on formation of widely differing products of petroleum, asphalt being derived from horizontal layers of bitumen, while gilsonite and grahamite are the result of changes occurring in narrow almost vertical veins. The asphalts contain more than 20 per cent of saturated hydrocarbons and the gilsonites and grahamites contain only a small amount.
322. ———. The origin of petroleum and asphalt. *Jour. Ind. and Eng. Chem.*, vol. 8, January, 1916, p. 4. Discusses theory of origin of all forms of petroleum by surface action between a natural gas and the sands with which it comes in contact, deduced from a study of the origin of asphalt from heavy petroleum by the surface action of a colloidal clay on soft bitumen.
323. TAYLOR, F. B. Theories as to origin of oil. *Oil and Gas Jour.*, vol. 11, May 25, 1916, pp. 30-31. Gives short reviews of organic and inorganic theories of White and Orton, and Moisson. Discusses also theory that pools are connected as if by forks of a stream, and oil sands were deposited as are the sands in beds of streams at present time.

See also Nos. 218, 262.

INORGANIC THEORY, see no. 323.

ORGANIC. 25✓

324. CHAUTARD, JEAN. The origin of petroleum. *Petroleum Rev.*, vol. 34, May 13, 1916, p. 398; May 27, p. 432. *Revue Sci.*, t. 54, Aug. 12-19, 1916, p. 501. Concludes that geology does not give any arguments favorable to a theory of inorganic origin of petroleum.
325. CUNNINGHAM-CRAIG, E. H. The origin of oil shales. *Proc. Roy. Soc. Edinburgh*, vol. 36, 1916, pp. 44-86. Discusses relation of oil-rocks and oil-shales and the composition of kerogen and oil-shale. Concludes that oil-shale fields and oil fields are closely connected.
326. MABERY, C. F. The relations of the chemical composition of petroleum to its genesis and geologic occurrence. *Econ. Geol.*, vol. 11, Aug.-Sept., 1916, pp. 511-527. Discusses proofs of the organic origin of petroleum, and considers the types of petroleum as related to varied geologic conditions of pressure and temperature and to contact with sulphur.

See also Nos. 218, 313, 323.

ACCUMULATION. 26o

327. DALY, M. R. The diastrophic theory. A contribution to the study of the mechanics of oil and gas accumulation in commercial deposits. *Bull. Am. Inst. Min. Eng.*, July, 1916, pp. 1137-1157; discussion, December, 1916, pp. 2204-2211. Reviews anticlinal and hydraulic theories of origin of petroleum. Explains diastrophic theory, assuming as a starting point the organic origin of petroleum found in pools. Gives interpretation of mechanism of the sealing of rock pressure in oil and gas pools.
- 327a. JOHNSON, R. H. The rôle and fate of the connate water in oil and gas sands. *Trans. Am. Inst. Min. Eng.*, vol. 51, 1916, pp. 597-592; discussion, pp. 592-610. Conclusions are that with depth an increase of gas is found and a decreased quantity of oil finds its way into the larger pores. See

also Bull. Am. Inst. Min. Eng., Feb., 1915, pp. 221-226; discussion, May 1915, pp. 1157-1162, July, 1915, pp. 1449-1459, Sept., 1915, pp. 2057-2060. (No. 343, 1915 Bibliography.)

- 328.** McCox, A. W. Some effects of capillarity on oil accumulation. Jour. Geol., vol. 24, Nov.-Dec., 1916, pp. 798-805. Points out the possibility that capillary forces have caused anticlines in nature.

See also Nos. 185, 197, 312.

OIL AND GAS RESERVOIR PRESSURE.

260.1

- 329.** COOPER, A. S. Closed pressure of gas wells. California Derrick, vol. 9, April, 1916, pp. 3-4. Gives short discussion of the relation between hydrostatic pressure and gas pressure, with diagrams.

APPLIED GEOLOGY.

270

- 330.** OIL AND GAS JOURNAL. Geological science applied to oil. Vol. 14, Jan. 18, 1916, p. 67. Discusses the value of scientific investigation over the old-fashioned methods of finding oil.
- 331.** STANDARD OIL BULLETIN. The geologist's part in oil production. Vol. 4, August, 1916, pp. 3-5, 12. Discusses selection of territory in California for development, the prospecting for deeper oil sands, and the relationship of water and oil sands in developed fields.

DETERMINATION OF OIL AND GAS FIELDS.

270.1

- 332.** JOHNSTON, JOHN, and ADAMS, L. H. On the measurement of temperature in bore-holes. Econ. Geol., vol. 11, December, 1916, pp. 741-762. Knowledge of the temperature gradient under the earth's crust may be of economic value and may aid in the discovery of coal or oil. Describes how such temperature may be accurately measured. The limits of accuracy of different kinds of thermometers are defined and methods of using them explained. Tabulated results are given for three wells.

PATENT.

- 333.** SQUIRES, FREDERICK. Method of locating natural gas. U. S. patent 1,108,757, Jan. 18, 1918.

DEVELOPMENT AND PRODUCTION (OIL AND GAS).

GENERAL TREATISES.

- 334.** GALPIN, S. L. Petroleum engineering. Iowa Engineer, vol. 17, November, 1916, pp. 45-48. Reviews briefly the development of an oil property and emphasizes the growing need for specialists and engineers in this field.
- 335.** HEGGEM, A. G. Petroleum producing. Sibley Jour. Eng., vol. 30, May, 1916, pp. 251-254. Describes methods used in the production and extraction of oil and gas.
- 336.** JOHNSON, R. H. Efficiency in the production of petroleum. The American Petroleum Industry, by R. F. Bacon and W. A. Hamor, New York, 1916, vol. 1, pp. 410-436. Discusses methods of leasing and paying royalties, keeping of logs, location of test wells, spacing of wells, and depths to which they should be drilled, pumping methods, stimulation of production, and control of wild wells.
- 337.** JOHNSON, R. H., and HUNTLEY, L. G. Principles of oil and gas production. New York, 1916, 371 pp. A general treatise, with reference chiefly to conditions in America.

See also Nos. 3, 314.

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See also Nos. 190, 216, 257.

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- 350. RAND, ED. Well-drilling apparatus. U. S. patent 1,168,226, Jan. 11, 1916.
- 351. RICHARD, L. L. Sand-pump for wells. U. S. patent 1,203,784, Nov. 7, 1916.
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- 355. WEATHERSBY, F. R. Drill. U. S. patent 1,206,488, Nov. 28, 1916.
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 413. STEPHENS, R. W. Combination drilling rig. U. S. patent 1,170,015, Feb. 1, 1916.
 414. WRIGHT, C. S. Bull-wheel for drilling apparatus. U. S. patent 1,170,131, Feb. 1, 1916.

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 416. OIL AGE. The new water-softening process. Vol. 12, July, 1916, pp. 9-10, 12-13. Describes process for softening boiler water; is applicable to California oil fields, where water is hard and impure.
 417. OIL AND GAS JOURNAL. Use of electricity in oil lease work. Vol. 14, Jan. 13, 1916, p. 61. Enumerates advantages of electricity, such as continuity of service, little need of repairs, etc.
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See No. 502.

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 - 421. GILMORE, JOSEPH. Leak-detector for oil well casings. U. S. patent 1,200,722, Oct. 10, 1916.
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 - 427. MOSER, F. J. Casing head for wells. U. S. patent 1,194,863, Aug. 15, 1916.
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 - 430. WALLACE, C. O. Well-casing puller. U. S. patent 1,180,351, June 6, 1916.
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 - 433. WHITNEY, C. W. Process of placing casing in wells. U. S. patent 1,180,516, July 4, 1916.
- PROTECTION AGAINST CORROSION, *see* Nos. 500-511.

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 - 435. TACITUS, V. A new method of checking water shut-offs. *Petroleum Rev.*, vol. 34, June 24, 1916, p. 509. Describes method of sinking into well a temporary column of 4-inch pipe, provided with a "stuffing box," which tightly closes well inside of casing. "Stuffing boxes" of Parker's system with leather bags are used.
- See also* Nos. 156, 157.

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- 437. McNALLEN, A. J. Tubing and packing for oil wells. U. S. patent 1,173,825, Feb. 29, 1916.
- 438. MOSER, E. J. Well packer. U. S. patent 1,198,649, Sept. 19, 1916.
- 439. MOSER, F. J. Well packer. U. S. patent 1,190,790, July 11, 1916.
- 440. RHEA, W. W. Well packer. U. S. patent 1,188,489, June 27, 1916.
- 441. ROBINSON, L. E. High-pressure-gas-well packer. U. S. patent 1,199,614, Sept. 26, 1916.
- 442. STINSON, J. C. Deep well packer. U. S. patent 1,779,971, Apr. 4, 1916.
- 443. SWEET, CALVIN. Water-stopping device for oil and other wells. U. S. patent 1,209,634, Dec. 19, 1916.

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See also Nos. 83, 85.

CONTROL OF LARGE WELLS AND WELLS ON FIRE.

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- 446.** HEGGEM, A. G. The control of petroleum and natural gas wells. *Trans. Am. Inst. Min. Eng.*, vol. 54, 1916, pp. 289-300. Describes the control casing head and discusses its use and advantages in oil and gas wells as a means of safeguarding workmen and of protecting property from destruction.
- 447.** MILLAR, ARTHUR. Oil well fires and how to prevent them. *Petroleum Rev.*, vol. 34, June 17, 1916, p. 492. Suggests use of specified table of distances between buildings and wells compiled by experienced operators; use of special non-return valves where gas is conveyed from the well for fuel; spark arresters on smithy cowls and boiler uptakes; good insulation, earthing, management of tools, ropes, etc., so as not to cause friction. Describes methods of extinguishing fires by heaping earth to form a crater around a flame issuing from a borehole; drawing off oil in pipes laid through an earthen wall, while keeping the wall moist with water.

See also Nos. 119, 220, 221, 273, 336.

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- 448.** GILBERT, G. G. Well plug. U. S. patent 1,167,289, Jan. 4, 1916.
- 449.** MILLER, D. C. Sealing plug for oil wells. U. S. patent 1,194,764, Aug. 15, 1916.
- 450.** PIERCE, E. P. Plug for oil holes. U. S. patent 1,169,189, Jan. 25, 1916.
- 451.** SAVAGE, G. M. Well shut off. U. S. patent 1,170,851, Feb. 8, 1916.
- 452.** SITZMAN, C. E. Apparatus for plugging wells. U. S. patent 1,190,024, July 4, 1916.

PRODUCTION (METHODS, EQUIPMENT, AND OPERATIONS).

- 453.** LIWEHR, A. E. Die Erdölförderung aus Bohrlöchern (Oil production from drilling). *Petroleum Ztschr.*, Jahrg. 11, May 17, 1916, pp. 811-818; June 7, pp. 866-872; June 21, pp. 927-933. Reviews the various systems of oil production, such as bailing, pumping, use of compressed air, natural gas, etc., and discusses the advantages of each.

See also Nos. 216, 408.

WELL RECORDS, COST, ETC., *see* Nos. 61, 62, 155, 214, 248, 336, 415.

PUMPING OIL WELLS.

See Nos. 154, 336.

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- 455.** BRADLEY, W. H. Pump for oil wells. Canadian patent 171,156, Aug. 1, 1916.
- 456.** BUTLER, C. A. Oil-well pump. U. S. patent 1,175,599, Mar. 14, 1916.
- 457.** CHAPMAN, M. T. Pumping machinery. U. S. patent 1,174,122, Mar. 7, 1916.
- 458.** ——— Pumping machinery. U. S. patent 1,174,121, Mar. 7, 1916.

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460. GARVER, OTTO, AND GRIDER, MARION. Oil well pump. U. S. patent 1,190,281, July 11, 1916.
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462. HAHN, JOHN. Oil-well equipment (pump tubing). U. S. patent 1,207,699, Dec. 5, 1916.
463. JONES, W. L. Deep-well pump. U. S. patent 1,181,457, May 2, 1916.
464. KNAPP, W. G. Oil or gas saver. U. S. patent 1,208,454, Dec. 19, 1916.
465. KNOKE, J. C. Well-tubing pump. U. S. patent 1,199,190, Sept. 26, 1916.
466. KROGH, F. W. Removable deep-well pump cylinder. U. S. patent 1,192,791, July 25, 1916.
467. POINDEXTER, W. S., AND WAGNER, M. E. Oil-pump jack. U. S. patent 1,209,023, Dec. 19, 1916.
468. RISDEN, H. J., and SEPPL, F. F. Fluid-release mechanism for well pumps. U. S. patent 1,182,858, May 9, 1916.
469. SINCLAIR, E. J. Well-flowing device. U. S. patent 1,209,505, Dec. 19, 1916.
470. TITUS, RICHARD. Stuffing-box for oil wells. U. S. patent 1,168,687, Jan. 18, 1916.
- See also Nos. 375, 436-440, 442.
- POWER, see Nos. 75, 153, 415, 417, 418; Other methods of oil production, swabbing, see No. 259.

CARE OF PRODUCING OIL WELLS.

CLEANING OUT.

See Nos. 418, 483.

PATENTS.

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472. MONROE, F. A. Device for cleaning oil wells. U. S. patent 1,196,700, Sept. 19, 1916. Described in Min. and Eng. World, vol. 45, Dec. 2, 1916, p. 952.

HEATING AND STEAMING—PATENT.

473. HUFF, W. D. Operating and reclaiming oil wells. U. S. patent 1,200,423, Oct. 3, 1916.

OPERATION OF WELLS WITH LOOSE SAND.

See No. 339.

PATENT.

474. WILEY, C. A. Sand trap for oil wells. U. S. patent 1,204,105, Nov. 7, 1916.

GAS WELLS.

475. LINDSAY, ROY. Wells and field lines. Nat. Gas Jour., vol. 10, February, 1916, pp. 58-59. Describes methods used by a Canadian company for tubing, packing, caring for and inspecting gas wells, and laying and re-pairing lines.

- 476. WYER, S. S.** When is the drilling of off-set wells for natural gas justifiable? Columbus, Ohio, 1916, 56 pp. Gives definitions of terms used and cost of operating wells. Discusses limits of reservoirs, acreage lease, rentals, and royalties, declining volume, questions of service, etc.
See also Nos. 481, 482.

PATENT.

- 477. FORDING, W. G.** Blow valve and operating means for gas wells. U. S. patent 1,182,083, May 9, 1916.
See also No. 441.
RECORDS AND COSTS, *see* Nos. 75, 154, 155.

PRODUCTION (GATHERING AND TREATMENT).

OIL—CLEANING AND TREATING FOR WATER, B. S., ETC.

- 478. FRANCIS, C. K.** Emulsified or cut petroleum. Jour. Ind. and Eng. Chem., vol. 8, August, 1916, pp. 682-684. Gives results of investigation to determine nature of emulsified oils produced in the Cushing, Oklahoma, field. Suggests methods for properly treating them to break the emulsion. Analysis of residue from cut oil from Bartlesville sand is given. Describes methods used in Oklahoma and California fields. A combination of electricity and hot water is used to separate emulsified petroleum.

GAS AND VAPORS.

- 479. PETROLEUM WORLD.** Novel method of trapping gas from oil well. Vol. 13, September, 1916, pp. 416-417. Describes concrete dome built over well to cover all gas seepages from the well and force them to escape through pipes to a point some distance away where the gas is burned.
See also Nos. 475, 921, 957.
- 480. WESTCOTT, H. P.** Handbook of casing-head gas. Erie, Pa., 1916, 274 pp. Discusses production, properties, and uses of casing-head gas. Describes casing-head gasoline plant and methods of its operation, transportation of the finished product, etc.

COMPRESSORS AND CONDENSERS.

- 481. WYER, S. S.** Development of the law relating to the use of gas compressors in natural gas production. Bull. Am. Inst. Min. Eng., February, 1916, pp. 263-279; discussion, May, 1916, pp. 946-952. A chronological arrangement of decisions, 1885 to 1912, relating to the use of gas compressors.
- 482. ———** Necessary use and effect of gas compressors on natural gas field operating conditions. Bull. Am. Inst. Min. Eng., Feb., 1916, pp. 281-297. Investigation in Ohio, with special reference to working pressure relations of gas wells discharging by natural rock-pressure flow without the use of compressors, and adjacent wells discharging to intake lines to gas-compressing stations.
RECORDS AND COSTS, *see* No. 415.

PRODUCTIVENESS OF OIL AND GAS WELLS AND LANDS.

- 483. HUNTLEY, L. G.** Possible causes of the decline of oil wells and suggested methods of prolonging yield. The American Petroleum Industry,

by R. F. Bacon and W. A. Hamor, New York, 1916, vol. 1, pp. 374-409. A revised and enlarged edition of Tech. Paper 51, U. S. Bureau of Mines, 1913, by L. G. Huntley. Discusses causes of decline under natural causes and those due to poor management. Gives methods of cleaning wells. *See also* No. 476.

ARTIFICIAL FACTORS, STIMULATION OF PRODUCTION.

See No. 336.

INCREASE OF PRESSURE BY AIR OR GAS.

484. OIL AND GAS JOURNAL. Compressed air increases production. Vol. 15, June 29, 1916, pp. 35-36. Gives proofs of success of compressed-air system in Muskingum Valley, Ohio. Reviews patents covering this system, from 1865 to date.
485. PETROLEUM WORLD. Making air drive oil to the well. Vol. 13, Jan., 1916, p. 32. Describes briefly "air process" for stimulation of production in declining wells.

PATENTS.

486. DUNN, I. L. Method of increasing the production of oil wells. U. S. patent 1,190,268, July 11, 1916.
487. ——— Method of producing hydrocarbon from hydrocarbon-bearing earth strata. U. S. patent 1,190,267, July 11, 1916.
488. SQUIRES, FREDERICK. Method of recovering oil and gas. U. S. patent 1,198,078, Sept. 12, 1916.

USE OF WATER.

489. OIL AND GAS JOURNAL. Flooding old oil territory. Vol. 14, Mar. 16, 1916, p. 2. Short description of process of water flooding in the old fields of the East as a means of forcing the oil out of the rocks. (*See also* No. 490.)
490. ——— "Flooding" process in old oil leases. Vol. 14, Apr. 20, 1916, p. 29. Criticism of the above article on flooding old oil territory. Emphasizes the importance of scientific investigation of sand and conditions before determining on a method of forcing out the oil.

WASTES AND CONSERVATION.

- 490a. ELY, R. T. Conservation and economic theory. Trans. Am. Inst. Min. Eng., February, 1916, pp. 458-473. Conservation defined and described. Some economic principles of conservation given. Need shown for commissions to carry out principles laid down in laws.
491. NATURAL GAS ASSOCIATION OF AMERICA. Report of the committee on conservation. Proc. 11th Annual Meeting, vol. 8, 1916, pp. 353-368; discussion, pp. 368-374. Discusses conservation of natural gas and gives an account of the progress made in Oklahoma due to the conservation law of 1915 in that State. *See* Oklahoma Session laws 1915, 398.
492. OIL AND GAS JOURNAL. Natural gas wasted in early periods. Vol. 14, Jan. 27, 1916, p. 33. Discusses failure in early times to realize the economic value of gas, the development of industry from 1872 and increase

of its use. Waste of gas in drilling operations and in consumption is also discussed.

493. RITCHIE, N. E. A plea for conservation of natural gas. *Fuel Oil Jour.*, vol. 7, March, 1916, p. 100. Tells briefly of need of conservation laws in Texas. Makes suggestions as to requirements of law.

See also Nos. 95, 434.

MINING SOLID BITUMENS, *see* Nos. 129, 189, 261, 262.

FINANCIAL APPRAISEMENTS, ROYALTIES, CONTRACTS, COSTS, PRICES.

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498. ———. The valuation of oil properties. *The American Petroleum Industry*, by R. F. Bacon and W. A. Hamor, New York, 1916, pp. 345-367; *Petroleum Age*, vol. 3, January, 1916, pp. 35-39; February, 1916, pp. 37-40. Considers the various factors in the income and outlay of an oil property, calculation of surplus income, and amortization, also best methods of valuation.
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See also Nos. 336, 476.

70064*—19—5

TRANSPORTATION, STORAGE AND DISTRIBUTION.

TRANSPORTATION.

PIPE LINES.

CONSTRUCTION AND MAINTENANCE.

501. COLLINS, A. L. Influence of viscosity in pumping crude oil. *Eng. News*, vol. 76, July 6, 1916, pp. 22-24. Discusses importance of viscosity factor in the design and operation of pipe lines rather than the gravity of the oil. Gives cost data for pipe-line construction. Ten years is considered the life of pipe line.
502. HADLEY, F. L. Welding in gas-main construction. *Proc. Nat. Gas Assoc. Am.*, vol. 8, 1916, pp. 275-280; discussion, pp. 280-295; *Nat. Gas Jour.*, vol. 10, October, 1916, pp. 851-852. Gives experience in using oxy-acetylene welding on a gas line and on the casing of "the deep well," 7,181 feet, at McDonald, Pa.
503. HALL, A. S. The high pressure system; the welding of high pressure mains. *Nat. Gas Jour.*, vol. 10, March, 1916, pp. 113-117. Describes gas-compression system at Springfield, Mass. Methods of welding are applicable to mains for natural as well as artificial gas. Costs are given of compressor station and laying of mains.
504. MILLER, S. W. Oxy-acetylene welding. New York, 1916, 237 pp. A comprehensive treatise on welding cast iron, steel, copper, brass, bronze, and aluminum by the oxy-acetylene method, with concise information as to equipment required for both welding and cutting by this process.
505. MURPHY, S. J. The transatlantic pipe line. *Petroleum World*, vol. 13, December, 1916, p. 588. Describes construction and maintenance of line.
506. PETROLEUM REVIEW. The "Murphy" submarine pipe line. Vol. 35, Oct. 21, 1916, pp. 325-328. Gives details of proposed oil pipe line between Ireland and the United States, its construction, working, maintenance, etc. See also Nos. 71, 72, 214, 216, 217, 475, 480.

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510. FRIEND, J. N. The relative corrodibilities of iron and steel. *Chem. News*, vol. 113, Jan. 21, 1916, pp. 33-35; Jan. 28, pp. 38-39. Discusses different kinds of corrosion and the factors involved in determining the

relative corrodibilities of iron and steel, concluding that the two metals are about equally resistant.

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STATION EQUIPMENT.

See Nos. 75, 501.

PATENT.

512. KERN, E. N. Liquid fuel dispensing apparatus. U. S. patent 1,177,870, Apr. 4, 1916.

LINE EQUIPMENT AND TOOLS—PATENTS.

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514. AINE, H. E. Pipe laying machine. U. S. patent 1,177,915, Apr. 4, 1916.
515. BOYD, FRED. Pressure regulator for gas lines. U. S. patent 1,174,661, Mar. 7, 1916.
516. CRUGER, E. B. Apparatus for discharging dangerous liquids and gases. U. S. patent 1,182,460, May 9, 1916.
517. FABIAN, JULIUS. Gas pressure regulator. U. S. patent 1,180,638, Apr. 25, 1916.
518. FLANDERS, W. W. Attachment for gas meters. U. S. patent 1,180,482, Apr. 25, 1916.
519. FLORENCE, JOHN, AND FRAUER, O. Pipe testing plug. U. S. patent 1,178,145, Apr. 4, 1916.
520. GEHRUNG, J. A. Gas valve. U. S. patent 1,167,000, Jan. 4, 1916.
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RECORDS AND STATISTICS, see No. 86; Financial costs, see Nos. 71, 72, 75.

TANK CARS AND TANK WAGONS.

527. MASTER CAR BUILDERS' ASSOCIATION. Report of the special committee on tank cars. *Proc. 50th Ann. Convention*, June 1916, pt. 1, pp. 404-448; discussion, pp. 449-464. Classifies tank cars according to their time of building and their use. Discusses safety appliances, safety valves, running boards, and anchorage. Gives transportation requirements, general specifications, tests, and inspection of cars of each of four classes.
- 527a. ———. Specifications for tank cars. *Proc. 49th Ann. Convention*, June, 1915, pt. 2, pp. 932-946. Gives specifications for ordinary tank car and special car for volatile inflammable products with vapor tension of more than 10 pounds per square inch at 100° F.

See also No. 921.

CONSTRUCTION AND MAINTENANCE—PATENTS.

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 529. LEVY, E. D., AND JACOBS, H. W. Tank car. U. S. patent 1,173,443, Feb. 29, 1916.
 530. MORRISON, A. M. Wagon tank. U. S. patent 1,183,025, May 16, 1916.
 531. OSTRANDER, A. E. Tank car. U. S. patent 1,199,816, Oct. 3, 1916.
 532. PAUL, J. T. H. Tank car. U. S. patent 1,170,560, Feb. 8, 1916.

WATER TRANSPORTATION.

TANK STEAMERS.

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CONSTRUCTION AND MAINTENANCE.

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535. WHITE, R. S. Tank steamer. U. S. patent 1,187,951, June 20, 1916.

RECORDS AND STATISTICS.

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STORAGE.

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See also Nos. 161, 162, 190, 225, 766.

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TANKS.

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547. POOR, G. H. Apparatus for storing and dispensing combustible liquids. U. S. patent 1,207,075, Dec. 5, 1916.
548. WILSON, J. H., and BENNETT, S. A. Top for oil tanks. U. S. patent 1,178,895, Apr. 11, 1916.

STEEL AND IRON.

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See also Nos. 87, 88, 225.

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551. WARNER, L. K. Tank. U. S. patent 1,191,629, July 18, 1916.

CONCRETE.

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See also Nos. 88, 225; Wooden, *see* No. 225.

PATENT.

553. MUNN, M. J. Oil-storage tank. U. S. patent 1,200,391, Oct. 3, 1916.
- See also* No. 549.

RESERVOIRS.

EARTHEN AND CONCRETE-LINED, *see* Nos. 161, 225.

See also No. 552.

TANK AND RESERVOIR EQUIPMENT—PATENTS.

- 554. **BOURELL, W. A.** Tank-draining mechanism. U. S. patent 1,195,181, Aug. 22, 1916.
- 555. **BROOKS, R. A.** Surface-discharge apparatus for tanks. U. S. patent 1,203,578, Nov. 7, 1916.
- 556. **BYERS, C. D.** Unloading apparatus for portable tanks. U. S. patent 1,199,739, Sept. 26, 1916.
- 557. **CRABTREE, E. F.** Outlet fitting for tanks. U. S. patent 1,171,706, Feb. 15, 1916.
- 557a. **CROMPTON, T. A.** Apparatus for ventilating, steaming, or fire-extinguishing in tanks containing inflammable liquids. English patent 14331, Oct. 11, 1915.
- 558. **GERAGHTY, J. P.** Valve-controlling device for tanks. U. S. patent 1,182,163, May 9, 1916.
- 559. **GRAVES, C. E.** Heating means for mineral oils. U. S. patent 1,173,107, Feb. 22, 1916.
- 559a. **GRIFFIN, F. A.** Safety hand-hole cover for steam boilers and air and oil reservoirs. U. S. patent 1,192,417, July 25, 1916.
- 560. **HOLMES, O. J.** Gas exhauster for oil tanks. U. S. patent 1,173,108, Feb. 22, 1916.
- 560a. **HOPKINS, A. G.** Plastic can positions which may be used for mending tanks containing hydrocarbons, etc. English patent 19,437, Sept. 4, 1914.
- 561. **STIER, HERMAN.** Joint for metal tanks. U. S. patent 1,196,490, Aug. 29, 1916.

TEMPORARY AND SMALL CONTAINERS.

- 562. **HELDT, P. M.** The garage business: buildings, equipment, methods. *Horseless Age*, vol. 37, May 1, 15, 1916, pp. 348-349, 394-396; June 1, 15, 1916, pp. 432-433, 474-476. Describes construction of underground tanks, piping of tanks, gasoline pumps, delivery nozzle and hose, filters, wheel tanks, etc. Also discusses several storage systems.
- 563. **MILLER, C. E.** Steel barrel equipment. *Oildom*, vol. 6, Sept. 1, 1916, p. 428. Gives briefly the advantages of steel over wooden barrels and mentions method of manufacture used by the Pressed Steel Tank Co. of Milwaukee.
- 564. **NESTER, F.** The passing of the wood barrel. *Texaco Star*, vol. 3, January, 1916, pp. 10-12. Discusses the advantages of steel barrels, the importance of thorough cleaning for second use, the sampling of oil, and inspection before shipment.
- 565. **WALL, T.** Steaming, cleaning and preparing wood barrels for shipment of oil. *Texaco Star*, vol. 3, January, 1916, pp. 8-9. Methods for making old barrels fit for use are described.

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- 566. **BUDROE, C. F.** Combined gasoline and oil tank. U. S. patent 1,177,378, Mar. 28, 1916.

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 568. HACKNEY, R. H. Metal barrel. U. S. patent 1,178,717, Apr. 11, 1916.
 569. KESSLER, LOUIS. Gasoline storage tank. U. S. patent 1,189,968, July 4, 1916.
 570. LUKENS, C. D. Receptacle for storing volatile liquids. U. S. patent 1,174,880, Mar. 7, 1916.
 571. McMARTIN, H. C. Oil drum. Canadian patent 168,649, Apr. 4, 1916.
 572. NICHOLSON, J. H. Metal barrel and the like. U. S. patent 1,168,545, Jan. 18, 1916.
 572a. STANDARD OIL Co. Metallic barrels. English patent 9,858, July 6, 1915.
 572b. TAPP, W. H. Cans for petrol, etc. English patent 18,116, Dec. 29, 1915.

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 LOSSES, *see* No. 224.

MEASUREMENT OF VOLUMES AND WEIGHTS, GAGING AND METERING.

578. ELECTRICAL WORLD. Fluid meters. Vol. 67, Apr. 15, 1916, p. 895. Describes a meter suitable for use with natural gas or oil, designed to measure the pressure difference across an orifice placed between a pair of flanges in a pipe line.
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- 592a. UNITED STATES BUREAU OF STANDARDS. Specifications and tolerances for weights and measures and weighing and measuring devices. Circular 61, 1916, 44 pp. Contains specifications for measuring pumps.
- See also Nos. 228, 227, 921.

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594. BENFORD, E. M. Gasoline gage. U. S. patent 1,206,196, Nov. 23, 1916.
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- 597. CLEWELL, C. W. Liquid gage. U. S. patent 1,185,985, June 6, 1916.
- 598. HUNTER, J. M. Liquid gage. U. S. patent 1,174,579, Mar. 7, 1916.
- 599. KING, H. B. Oil-tank gage. U. S. patent 1,194,846, Aug. 15, 1916.
- 600. LIESE, H. M. Device for measuring and for regulating the flow of fluids—liquid or gaseous. U. S. patent 1,177,193, Mar. 28, 1916.
- 601. MACKENZIE, J. A., and MACKENZIE, G. W. Liquid-measuring apparatus. U. S. patent 1,179,857, Apr. 18, 1916.
- 602. OESCHGER, W. I. Gasoline gage. U. S. patent 1,172,481, Feb. 22, 1916.
- 603. PRICE, J. A. Fluid-measuring device. U. S. patent 1,180,183, Apr. 18, 1916.
- 604. SCHULTZ, E. H. Liquid-level indicator. U. S. patent 1,192,693, July 25, 1916.
- 605. TANNER, P. E. Gage for liquid-containing tanks. U. S. patent 1,179,471, Apr. 18, 1916.
- 606. ——— Gage for liquid-containing tanks. U. S. patent 1,201,527, Oct. 17, 1916.
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- 609. WERNER, E. E. Apparatus for indicating the volumetric flow of a gas. U. S. patent 1,195,631, Aug. 22, 1916.
- 610. WESTCOTT, H. P. Gas-volume measuring apparatus. U. S. patent 1,172,067, Feb. 15, 1916.
- 611. WILKINSON, C. P. Liquid-indicating gage. U. S. patent 1,193,744, Aug. 8, 1916.
- 612. WOOD, E. H. Gage for fluids or liquids. U. S. patent 1,186,260, June 6, 1916.

FIRE HAZARDS AND PREVENTION.

- 613. AUTOMOBILE. How pouring gas creates electricity. Vol. 84, Feb. 24, 1916, p. 385. Describes cause of fires at filling stations, even when no chamolis is used, by static electricity jumping from the funnel of the can to the faucet. Suggests precautions to be taken.
- 614. BOWIE, C. P. Foam system installation for fighting oil fires. Eng. News, vol. 75, April 27, 1916, pp. 794-797. Describes method of protecting oil storage tanks from fire by use of two chemical solutions. These solutions are combined and produce a thick, tenacious foam, which spreads over the burning oil, excluding air and extinguishing the flame. Gives formulas for solutions and details of plant at Coalinga, Cal.
- 615. Bureau for the Safe Transportation of Explosives and other Dangerous Articles. Report of the chief inspector, February, 1916. 1916, 85 pp. Gives statistics in regard to fires in the transportation of gasoline and other inflammable liquids during the year 1915. Reproduces circular letters issued by the Bureau relative to liquefied petroleum gas and to gasoline-storage locations. Contains a report on the Ardmore, Okla., gasoline explosion.
- 616. FUEL OIL JOURNAL. How the Millway fire was put out. Vol. 7, September, 1916, p. 37. Report on oil-tank fire extinguished by the foamite system.
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623. OIL AND GAS JOURNAL. New plan for extinguishing fires. Vol. 15, June 15, 1916, p. 31. Describes a new foam system. The acid and soda are mixed at entrance of the tank and forced upward to a float that at all times is upon the surface of the oil. The mixture is ejected from circular float, directly to the oil.
624. PETROLEUM AGE. To put out small fires. Vol. 3, April, 1916, p. 14. Describes English invention for extinguishing fires which are due to ignition of gasoline vapor. Sawdust mixed with bicarbonate of soda has advantages over sand as an extinguishing medium.
625. SCIENTIFIC AMERICAN. Extinguishing oil tank fires with a blanket of foam. Vol. 115, July 8, 1916, p. 44. Describes a liquid extinguisher called "fire foam." The foam consists of two liquors which, when mixed, form a thick spume and spreads over a wide area shutting off the oxygen supply of burning oil. One of the liquors is of an alkaline nature, and the other contains soda; Greek licorice is used as a binder for the two liquids.
- See also Nos. 120, 220, 221, 538, 552.*

PATENTS.

626. GUNTORPE, C. H. Lightning protecting system for oil tanks. U. S. patent 1,175,749, Mar. 14, 1916.
627. HOLMES, O. J. Fire prevention apparatus for oil tanks. U. S. patent 1,177,331, Mar. 28, 1916.
628. JONES, TOLBERT. Oil-tank protector. U. S. patent 1,198,850, Sept. 19, 1916.
629. REED, R. H. Safety apparatus for oil wells (tanks). U. S. patent 1,191,229, July 18, 1916.

SAMPLING.

See No. 589.

PATENT.

630. ROBBISON, WILLIAM. Liquid-sampler. U. S. patent 1,166,717, Jan. 4, 1916.

LEGISLATION AND REGULATION.

631. PETROLEUM REVIEW. How the common carrier policy for pipe lines has operated. Vol. 34, Apr. 15, 1916, pp. 315-316. Shows the unsatisfactory results of common carrier policy. Figures are quoted from Wall Street Journal of net profits of pipe-line companies for 1913 and 1915, eastern lines.
- See also Nos. 527, 527a.*

PROPERTIES AND THEIR DETERMINATION.

- 632.** HUBBARD, PRÉVOST. Laboratory manual of bituminous materials for use of students in highway engineering. New York, 1916, 153 pp. Discusses various tests and methods for making bituminous materials, and gives characteristics of the more important bitumens.
- 633.** PULLAR, H. B. Identification of bituminous materials. Oildom, vol. 6, March, 1916, pp. 130-132. States characteristics of bituminous materials that are used in the construction of roads and pavements, waterproofing, insulation, etc., and discusses their derivation.
- See also* Nos. 3, 214, 314, 320, 326, 784, 1346.

PHYSICAL PROPERTIES.

DENSITY (SPECIFIC GRAVITY) AND COEFFICIENT OF EXPANSION.

- 634.** BELL, H. W. Relation of specific gravity to degrees Baumé. West. Eng., vol. 7, March, 1916, p. 90. Formulas are given for correct calculations.
- 635.** FORREST, C. N. Limitations of results of tests of bituminous materials. Canadian Engineer, vol. 30, Feb. 24, 1916, pp. 277-280. Discusses tests for specific gravity, flash point, etc., methods and apparatus used, and the limitations of results of these tests.
- 636.** UNITED STATES BUREAU OF STANDARDS. Standard density and volumetric tables. Circular 19, Mar. 30, 1916, 5th ed., 67 pp. Contains density tables for oils, also conversion tables for degrees Baumé and specific gravity for liquids lighter than water and for liquids heavier than water.
- 637.** ——— United States standard Baumé hydrometer scales. Circular 59, Apr. 5, 1916, 13 pp. Gives formulas showing the relation between Baumé degrees and specific gravity, and tables of corresponding values for liquids heavier than water and liquids lighter than water. Discusses use of American standard by manufacturers of hydrometers.
- See also* Nos. 8, 9, 684, 740, 750, 752, 754, 756, 767.

THERMAL.

SPECIFIC HEAT AND LATENT HEATS.

- 638.** BAYARD, H. T. Heat from fuel oil. Petroleum, vol. 1, July, 1916, p. 29; August, p. 39; September, pp. 23-24; October, p. 51. Discusses the fundamental principles of heat and the use of thermometers and pyrometers. Describes Joule's apparatus for measuring work in heat. Discusses also the loss of heat in steam, internal combustion, and oil engines. Gives formula for determining the heating value of fuels and the results of a test of Cushing oil. Efficiency of oil is compared with that of coal.
- 639.** EABHANT, R. F. The ratio of the specific heats and the coefficient of viscosity of natural gas from typical fields. Jour. Am. Soc. Mech. Eng., vol. 38, November, 1916, pp. 888, 890. Gives results of study to secure measurements of products like those studied in tests of Boyle's law.
- See also* No. 767.

BOILING POINTS AND VAPOR PRESSURES, EVAPORATION, VOLATILITY, FRACTIONAL DISTILLATION.

640. EDWARDS, A. The estimation of benzene and toluene in commercial mixtures. *Jour. Soc. Chem. Ind.*, vol. 35, May 31, 1916, pp. 587-590. Describes method depending on separation of the constituents of naphtha in pairs (benzene-toluene and toluene-xylene) by fractional distillation. Describes, also, determination of boiling points and boiling point composition by reference to curves made from known mixtures.
641. O'NEILL, J. G. Fractional distillation of lubricating oils. *Jour. Am. Soc. Naval Eng.*, vol. 28, May, 1916, pp. 465-486. Describes investigations at the Naval Engineering Experiment Station, Annapolis, Md., to devise a fractional distillation method for separating a mineral lubricating oil into its component light and heavy oils, and to investigate the properties of these light and heavy oils. Apparatus, method of procedure (distilling by aid of heat and superheated steam), and results are given.
642. RITTMAN, W. F., and DEAN, E. W. The analytical distillation of petroleum. *Bull. 125, U. S. Bureau of Mines*, 1916, 79 pp. Presents results of experiments made to ascertain a standard method of analytical distillation, a study of efficiencies of types of fractionation apparatus now in use, and effect of cracking as a factor in analytical distillation of petroleum in still heads.
643. TICE, P. S. Vaporization of motor fuels. *Horseless Age*, vol. 37, June 1, 1916, pp. 434-437; June 15, 1916, *Eng. sec.*, pp. 10-13. Explains theory of vaporization and its application to different petroleum distillates. Formulas are given for vaporization calculations and numerous curves showing the vaporization characteristics of fuels of the paraffin series. Discusses the mechanism of heat transfer, methods of heat supply, etc.
- See also* Nos. 670, 684, 685, 739, 767.

MELTING POINTS, CRYSTALLIZATION, COLD TESTS, CONGEALING POINT.

644. DOAN, W. S. Lubricating oils for ammonia compressors. *Steam*, vol. 18, November, 1916, pp. 133-134. Discusses care in the use of lubricating oils and the importance of the cold test of the oil before using. States that petroleum oils are the best from which to select lubricants of this kind.
645. GOLODETZ, L. Schmelzpunktbestimmung von Fetten und Wachsen (Melting point determination of fats and waxes). *Chem. Ztg.*, Jahrg. 40, Mar. 11, 1916, p. 223. Describes a new method, giving its advantages.
646. PECZALSKI, THADÉE. Effect de la température sur la structure des paraffines (Effect of temperature on the structure of paraffins). *Compt. rend.*, t. 162, May 15, 1916, pp. 784-786. Describes changes, such as increases in density, crystallization, etc.
- See also* Nos. 115, 659, 661, 664, 767.

LUBRICATING VALUE.

647. BATTLE, J. R. Lubricating engineer's handbook; a reference book of data, tables and general information for the use of lubricating engineers, oil salesmen, operating engineers, mill and power-plant superintendents, and machinery designers, etc. Philadelphia, 1916, 333 pp. Discusses the theory of lubrication, the manufacture of lubricants from various oils, etc.
648. ———. Lubrication engineering. *Power*, vol. 43, Mar. 21, 1916, pp. 405-406. Emphasizes the importance of checking deliveries of oil and of conducting efficiency tests of oils. Methods for tests are described.

649. CONOVER, W. R. Lubricating oils and cutting compounds for shop use. *Am. Machinist*, vol. 44, June 8, 1916, pp. 998-998. Discusses the selection of lubricating oils and tests that should control their quality.
650. FLOWERS, A. E. Viscosity and its relation to lubricating value. *Power*, vol. 43, Jan. 11, 1916, pp. 37-40. Explains what is meant by viscosity and the effect of that property upon the "body" and lubricating value of an oil.
651. GILL, A. H. Lubricating oils. *Prac. Eng.*, vol. 20, Aug. 1, 1916, pp. 661-662; *Oilodom*, vol. 6, February, 1916, pp. 86-88. Address before the Detroit Engineering Society. Gives desirable characteristics of lubricating oils and methods of testing.
652. GURWITCH, L. The theory of lubrication. *Petroleum Rev.*, vol. 35, Dec. 30, 1916, p. 534; vol. 36, Jan. 6, 1917, p. 13. Supports the theory of viscosity as opposed to the hydrodynamic theory of Ubbelohde and others.
653. HERSCHEL, W. H. Lubricating value of oils. *Oilodom*, vol. 6, May, 1916, pp. 241-243. Presents evidence against the property known as "body," and concludes that oils of the same viscosity should be equally valuable in a given bearing.
654. ——— Quantitative test for resistance of lubricating oils to emulsification. *Proc. Am. Soc. Test. Materials*, vol. 16, pt. 2, 1916, pp. 248-265; discussion, pp. 266-272. Gives proposed emulsification test for oils, which is calculated to increase the efficiency of lubricating oils in forced-feed lubrication. Describes method and apparatus, explains the theory of emulsification, and shows the relation between demulsibility, or the maximum rate of settling, and other physical properties of oils and between demulsibility and chemical tests. Concludes that oils of high demulsibility give the most satisfactory service.
655. HILPP, E. H. The lubrication of steam and internal-combustion engine cylinders. *Oilodom*, vol. 6, April, 1916, pp. 198-194. Gives a short discussion of suitable oils and their compounding.
656. KAUFFMAN, J. L. Lubricating oils. *Jour. Am. Soc. Naval. Eng.*, vol. 28, August, 1916, pp. 692-707. Deals with lubricating oils used in marine service. Describes chemical, physical, and practical tests on all oils purchased for the use of the Navy.
657. MANN, F. W. Lubrication and lubricating oil. *Oilodom*, vol. 6, January, 1916, pp. 36-40. Enumerates qualities necessary in good lubricating oils, and discusses their manufacture; also discusses hydrocarbons and their value in the oils.
658. MORGAN, J. D. Lubricants and lubrication. *Power*, vol. 43, Mar. 7, 1916, pp. 317-318. Discusses the characteristics of a good lubricant and methods of testing oils.
659. MOTOR. Testing of lubricants. Vol. 26, May, 1916, pp. 78-79. Describes series of simple experiments to determine definitely the value of the oils and other lubricants used in the car. Flash, heat, emulsion, viscosity, and cold tests are described.
660. NATIONAL PETROLEUM NEWS. Fire test no check on lubricating value. Vol. 7, January, 1916, pp. 70-71. Explains why the ability of an oil to meet mechanical conditions has little to do with fire tests, which originated when kerosene was the only product of petroleum.
661. ——— Poor oil plays havoc with ice machines. Vol. 8, June, 1916, pp. 50-53. Discusses importance of using an oil of extremely low cold test and at the same time of moderately high flash and fire test, in order that oil will not congeal and will withstand the temperature developed in the condenser cylinder.

662. PARR, S. W. The chemical examination of water, fuel, flue gases, and lubricants; a course for engineering students. University of Illinois, 1916, 180 pp.
663. PETTY, H. W. Lubricating oils and their functions. *Petroleum Rev.*, vol. 34, May 6, 1916, pp. 369-370; May 13, p. 391. Classifies lubricants and describes tests. Discusses kinds of lubrications and the type of oil necessary for each, also, the necessity, advantages, and types of oil-testing machines.
664. ROSEMAN, BRUNO. Schmieröle für Dieselmotoren (Lubricating oils for Diesel motors). *Petroleum Ztschr.*, Jahrg. 11, June 7, 1916, pp. 372-376. Discusses the demands on a lubricating oil in Diesel engines, methods of using the oil, and the various tests to be applied, such as viscosity, specific gravity, cold test, melting point, etc.
665. SCOTT, A. C. Lubrication of station and industrial machinery. *Electrical World*, vol. 87, Apr. 8, 1916, pp. 817-819; May 13, pp. 1094-1096; June 10, pp. 1351-1352. Discusses satisfactory lubrication and analyzes the requirements of different bearing surfaces. Gives the essential characteristics of commercial lubricants. Makes suggestions as to the storage, filtration, and recovery of lubricating oil.
666. SLAUGHTER, W. B. Lubricating-oil testing machine. *Am. Machinist*, vol. 44, Jan. 13, 1916, pp. 71-72. Describes machine designed for commercial work; its merits are the method of applying the load and reading of the torque developed, and the ready determination of the coefficient of friction.
667. SMITH, G. A. Comparative quality of oils. *Power*, vol. 43, June 13, 1916, p. 848. Gives mathematical rule for rating lubricating oils. (*See also* No. 668.)
668. SMITH, H. R. Comparative quality of oils. *Power*, vol. 44, Sept. 19, 1916, p. 426. Reply to letter of G. A. Smith (*see* No. 667), showing the impracticability of combining the chemical and physical characteristics of a lubricating oil to form an empirical mathematical rule for the determination of quality.
669. THORP, L. E. Viscosity, its relation to quality in lubricating oils. *Oil-dom*, vol. 6, April, 1916, pp. 190-193, 296. Address before Western Oil Jobbers' convention, St. Louis. Emphasizes the importance of using a standard temperature representing using conditions in comparing oils in regard to viscosity. Describes practice in determining viscosity, and discusses its importance over all other tests for cylinder oils, lubricants, oils for filtering systems, etc.
670. UPRON, G. B. The properties of oils and their relation to lubrication. *Sibley Jour. Eng.*, vol. 30, June, 1916, pp. 277-282. Discusses the meanings and purposes of various tests for lubricating oils, such as tests for acidity, ash, carbon residue, oxidation, volatility, surface tension, color, emulsion, flash and burning points, heat test, etc.
- See also* Nos. 115, 641, 644, 739, 981, 1017.

OTHER PROPERTIES OF LIQUIDS.

671. CONRADSON, P. H. Emulsification of mineral lubricating oils; apparatus and test method. *Proc. Am. Soc. Test. Materials*, vol. 16, part 2, 1916, pp. 273-279; discussion, pp. 280-281. Describes simple laboratory apparatus and test method for determining the emulsibility and demulsification value of lubricating oils, such as steam-turbine, steam-engine, and crank-case oils.

672. EGLOFF, GUSTAV AND MOORE, R. J. Viscosity of a thermolized paraffin base oil. *Met. and Chem. Eng.*, vol 15, Aug. 15, 1916, pp. 192-193. The oil was subjected to temperatures from 500° to 700° C., and rates of flow from 12 to 36 gal. per hour. The viscosity of the decomposed oil increased with increase of temperature, then decreased as the temperature increased. The maximum in viscosity 1.245 was at 600° C. and constant rate of flow 12 gal. per hour. The minima of 1.104 at 500° C. and 1.055 at 700° C. at same rate are recorded. Effect of rate of oil flow was determined. The minimum in the viscosity was 0.906 at 22 gal. per hour and maxima of 1.330 at 12 gal. per hour and 1.161 at 36 gal. per hour.
673. HAYES, H. C., AND LEWIS, G. W. The measurement of viscosity and a new form of viscosimeter. *Trans. Am. Soc. Mech. Eng.*, vol. 38, 1916, pp. 383-396; discussion, pp. 396-405. The coefficient of viscosity is defined and a working formula developed for its determination. Various types of meters are described.
674. HERSCHEL, W. H. Brief description of the test for demulsibility or resistance of an oil to emulsification with water, as developed by the Bureau of Standards. *Oildom*, vol. 6, May, 1916, pp. 243-244. Describes test applicable to non-emulsifying oils, for high-speed engines and turbines. Twenty c. c. of oil and 40 c. c. of water are placed in a 100 c. c. cylinder having an inside diameter of 1 inch and heated to 55° C. The oil and water are mixed by stirring with a paddle for five minutes at a speed of 1500 r. p. m. The paddle is a metal plate $3\frac{1}{2}$ in. by $\frac{1}{2}$ in. by $\frac{1}{8}$ in. thick.
675. HERSEY, M. D. The theory of the torsion and rolling-ball viscosimeters, and their use in measuring the effect of pressure on viscosity. *Jour. Wash. Acad. Sci.*, vol. 6, Sept. 19, 1916, pp. 525-530. Explains construction and use of the instrument and describes experimental tests of the theory, giving results on two lubricating oils.
676. HOLDZ, D. Die Leitfähigkeit und elektrische Erregbarkeit von Benzin, Benzol und ähnlichen feuergefährlichen Flüssigkeiten (The conductivity and electrical excitability of benzine, benzol, and similar combustible liquids). *Petroleum Ztschr.*, Jahrg. 11, Feb. 2, 1916, pp. 425-429. Gives results of the calculation of the theoretical time of discharge of electrically excited benzine from the conductivity and density. Asserts that there is no danger from explosion when the conductors holding the benzine are grounded.
677. LELICH, F. T. De-emulsibility testing of engine oils. *Power*, vol. 43, Feb. 29, 1916, pp. 294-295. Describes test upon which United States Bureau of Standards has been working. A mixture of 20 c. c. of oil and 40 c. c. of water is stirred for five minutes in a cylinder 1 in. in diameter, the stirring being done by a flat paddle $\frac{1}{2}$ in. wide by $3\frac{1}{2}$ in. long rotated at 1,500 r. p. m. The demulsibility is determined by noting the rate of separation of oil and water and is expressed in cubic centimeters of separation per hour. (See also No. 683.)
678. McILHINEY, P. O. The unit of viscosity measurement. *Jour. Ind. and Eng. Chem.*, vol. 8, May, 1916, pp. 433-435. To overcome the lack of uniformity in measurement of viscosity, the use of the term "poise" is suggested to express the unit of viscosity in C. G. S. units, with decimal multiple and sub-multiples expressed as "centipoise," etc. Gives table of the relation between readings of the Engler, Saybolt and Redwood viscometers.
679. OILDOM. The ignition of gasoline by electricity. Vol. 6, Aug., 1916, pp. 380, 382. Discusses ignition by sparks of static electricity. Concrete examples are given to show the real danger and three ways of generating

- electricity in handling gasoline are explained. Article is reprinted from "Travelers' standard."
680. POWER. Flow of oil through orifices. Vol. 44, July 11, 1916, pp. 58-59. Gives measurements of flow of fuel oil, power distillate, and Kansas crude under different pressures and through different sized orifices. The results are from experiments made at Iowa State University to obtain data applicable to oil-injection devices.
681. RICHARDS, T. W., AND SHIPLEY, J. W. The compressibility of certain typical hydrocarbons, alcohols, and ketones. Jour. Am. Chem. Soc., vol. 38, May, 1916, pp. 989-999. Describes an accurate, but simple, pressure gage. Gives data for the compressibility of 15 organic liquids, including benzene and toluene.
682. SAVILL, C. A., AND COX, A. W. On the viscosity of oils in the Redwood and Ostwald viscometers. Jour. Soc. Chem. Ind., vol. 35, Feb. 15, 1916, pp. 151-153. Gives method for converting viscosity determined in an Ostwald viscometer into viscosity determined in a Redwood viscometer, or vice versa, and also an improved method of calibrating the Ostwald viscometer.
683. STRATTON, S. W. Testing the demulsibility of engine oils. Power, vol. 43, Apr. 4, 1916, p. 485. Discussion of an article by F. T. Leilich (*see* No. 677). Correction of statements and explanation of demulsibility tests as developed and used by the United States Bureau of Standards.
- See also* Nos. 115, 478, 501, 639, 650, 652-654, 659, 669, 670, 684, 685, 767, 1308, 1309, 1313.

OTHER PROPERTIES OF SOLIDS.

684. AMERICAN SOCIETY FOR TESTING MATERIALS. A. S. T. M. standards. Philadelphia, 1916, 737 pp. Includes standard tests for soluble bitumen, penetration of bituminous materials, loss on heating of oil and asphaltic compounds, and a standard method for distillation of bituminous materials suitable for road treatment.
685. ——— Report of Committee D-4, on road materials. Proc., vol. 16, part 1, 1916, pp. 300-305. Contains proposed revised standard tests for penetration of bituminous materials, for loss on heating of oil and asphaltic compounds, methods for distillation of bituminous materials suitable for road treatment, for determining the softening point of bituminous materials other than tar products; and tentative definitions of terms applicable to materials relating to roads. For tests *see* No. 684.
686. ——— Report of Sub-committee, of committee D-4, on penetration of bituminous materials. Proc., vol. 16, pt. 1, 1916, pp. 306-315. (*See also* No. 685.)
687. ——— Tentative method for determination of softening point of bituminous materials other than tar products. Proc., vol. 16, pt. 1, 1916, pp. 549-550. Describes ring-and-ball method.
688. AMERICAN SOCIETY OF CIVIL ENGINEERS. Progress report of the special committee on materials for road construction and on standards for their test and use. Proceedings, vol. 42, December, 1916, pp. 1611-1642. Specifications are given for the various materials.
689. CROSSLEY, T. L. Note on ductility test of asphalt. Jour. Ind. and Eng. Chem., vol. 8, Jan., 1916, p. 89. In tests on briquets, differences in asphalts are shown by using two speeds, 5 centimeters per minute and 10 centimeters per minute, and pulling to 110 centimeters.

690. HUBBARD, PRÉVOST. What the highway engineer should know about bituminous materials. Cornell Civil Engineer, vol. 24, March, 1916, pp. 260-278. Gives classification of bituminous materials used in highway engineering and their general properties. Reviews refining processes and discusses tests and specifications for these materials.
691. HUBBARD, PRÉVOST, AND PRITCHARD, F. P. Effect of controllable variables upon the penetration test for asphalts and asphalt cements. Jour. Agr. Research, vol. 5, Jan. 24, 1916, pp. 805-818; reprint by U. S. Dept. of Agr., 1916, 16 pp. Describes tests made to determine what effect apparently slight differences in temperature, load and time produce and to study the importance of other variables.
- See also Nos. 632, 633, 635, 646, 745, 771, 772, 774.

CHEMICAL PROPERTIES.

THERMOCHEMICAL.

FLASH AND BURNING POINTS, IGNITION POINTS, AND IGNITION MIXTURES.

692. BURRELL, G. A., AND BOYD, H. T. Quantity of gasoline necessary to produce explosive vapors in sewers. Tech. Paper 117, Bureau of Mines, 1916, 18 pp. Gives results of tests conducted in Pittsburgh, Pa.
693. EWELL, A. W. Gasoline, chamols and sparks. Jour. Worcester Polytech. Inst., vol. 19, May, 1916, pp. 315-317. Describes experiments to prove that the passage of gasoline through chamols does not give rise to potential differences sufficient to produce sparks and cause explosions.
- 693a. HOLDE, D. Weiteres über die Entladung durch Ströme in engen Röhren elektrisch erregten Benzins in geerdeten Auffanggefäßen (Further observations on discharges caused by electrically charged benzine flowing through narrow pipes into an earthed catch-vessel). Ztschr. Elektrochem., Jahrg. 22, 1916, pp. 195-199; Chem. Zentr., 1916, 1, p. 1285; Chem. Abs., vol. 11, Apr. 10, 1917, pp. 885-886. Discusses danger of fires from this cause; suggests earthing of vessels, and adding a little acetic acid to liquid to increase conductivity.
694. MARTINI AND HÜNEKE. Conditions for the formation of explosive mixtures of benzene with air. Chem. Ztg., Jahrg. 40, 916, pp. 948-949; Jour. Soc. Chem. Ind., vol. 35, Dec. 15, 1916, p. 1212. Shows that mixtures of benzene vapor with air explode within wider limits than mixtures of petroleum spirit with air. Petroleum-spirit mixtures containing from 2.4 to 4.9 per cent. were explosive. Mixtures of benzene vapor with air, explosibility limits were from 2.7 to 6.5 per cent.
- See also Nos. 115, 635, 659-661, 670, 742, 767.

CALORIFIC POWER AND CALORIMETRY.

695. GRADY, W. H. Selecting and buying fuel. Proc. Am. Wood. Preservers' Asso., 1916, pp. 91-99; discussion, pp. 99-103. Describes method of finding the most economical fuels on the basis of the cost per 25,000,000 B. t. u. Gives "purchasing engineer's fuel chart" showing use in comparing the heat values of coal, oil and gas fuels.
696. PATERSON, J. H. Fuel values. Jour. Soc. Chem. Ind., vol. 35, Jan. 15, 1916, pp. 10-12. Compares fuels including oil fuel as to amount of heat that can be obtained from them by the expenditure of a definite amount

of money. The number of thermal units per penny is designated as the absolute heat value.

697. POWER. Heat value of fuels. Vol. 43, June 6, 1916, p. 790. Gives a table showing, for various fuels, solid, liquid and gaseous, the heat units per pound, relative values, and pounds of water evaporated per pound.
698. TAMARU, SETSURO. On the experimental technics of calorimetric measurements at high temperatures. Jour. Soc. Chem. Ind., vol. 35, Jan. 31, 1916, pp. 81-88. Gives description of apparatus used and methods and formulæ for measurement.
699. UNITED STATES BUREAU OF STANDARDS. Standard methods of gas testing. Circular 48, 1916, 2nd. ed. 202 pp. Presents standard methods for testing of heating values, measurement of volumes, candlepower determination, etc. Describes laboratories and equipment necessary for official testing.
- See also* Nos. 638, 659, 741, 743, 757.

ILLUMINATING POWER, BURNING QUALITIES AND PHOTOMETRY, *see* Nos. 699, 739.

THERMAL DECOMPOSITION OR "CRACKING."

700. DAVIES, E. L. Experiments on the production of gasoline from hydrocarbon oils of high boiling points. Jour. Ind. and Eng. Chem., vol. 8, Feb., 1916, pp. 114-118. Describes apparatus experiments for determining the best conditions for cracking the oil and for saturating with hydrogen those portions converted into unsaturated compounds.
701. EGLOFF, GUSTAV. The thermal and pressure decomposition of pentanes and hexanes. Met. and Chem. Eng., vol. 15, Dec. 15, 1916, pp. 692-696. In order to ascertain the mechanism of aromatic hydrocarbon formation from paraffins and to study the elimination from petroleum oils of fractions not conducive to their formation, a mixture of pentanes and hexanes was studied with reference to the liquid products, benzene, toluene, xylene, naphthalene and anthracene, resulting from their decomposition.
702. ——— The thermal decomposition of the aliphatic hydrocarbon derivatives of naphthalene. Met. and Chem. Eng., vol. 15, Aug. 1, 1916, pp. 125-127. Gives results of an investigation of effect of pressure and temperature on formation of benzene and toluene from a tar oil composed mostly of aliphatic derivatives of naphthalene.
703. EGLOFF, GUSTAV, AND MOORE, R. J. Catalysis in the formation of gasoline from kerosene. Met. and Chem. Eng., vol. 15, July 15, 1916, pp. 67-79. Gives results of investigation of the catalytic effect of chloride of metals and non-metals upon the formation of gasoline from a paraffin-base kerosene and discusses the probable mechanism of the reaction.
704. ——— The effect of aluminum chloride upon a naphthene base oil in the formation of gasoline, unsaturated and aromatic hydrocarbons. Met. and Chem. Eng., vol. 15, Sept. 15, 1916, pp. 340-350. Gives a detailed description of experiments and full data of results.
705. EGLOFF, GUSTAV AND TWOMEY, T. J. The effect of temperature on the formation of benzene, toluene, xylene, naphthalene, and anthracene from petroleum at atmospheric pressure. Jour. Phys. Chem., vol. 20, February, 1916, pp. 121-150. Reviews work done on the cracking of petroleum for the aromatic hydrocarbons. Describes the apparatus and procedure in experiments with a gas-oil distillate from Pennsylvania crude. Describes changes with increased temperature and percentage of hydrocarbons formed.
706. ——— The effect of temperature on the formation of olefins from petroleum at atmospheric pressure. Met. and Chem. Eng., vol. 14, Mar. 1,

1918, pp. 247-250. In order to show the influence of temperature on the unsaturated hydrocarbon formation in certain distillation cuts, a gas oil from Pennsylvania crude was cracked in the gas state by passing it through a steel tube at atmospheric pressure at temperatures from 450° to 800°. The method of procedure is explained and the results are given.

707. — The formation of aromatic compounds from the cracking of a gas oil. *Met. and Chem. Eng.*, vol. 15, July 1, 1918, pp. 15-18. Describes experiments made to determine the yields of the aromatic hydrocarbons, benzene and toluene, from the cracking of a gas oil at atmospheric pressure, various temperatures, and at a constant rate of flow. The conclusion is that benzene, toluene, and xylene, relatively free from paraffin hydrocarbons, can be produced.

708. — The production of aromatic hydrocarbons from paraffin wax. *Jour. Phys. Chem.*, vol. 20, June, 1916, pp. 515-521. The cracking of paraffin wax by passing through a heated tube, or the gas-phase method, was used to show the possibility of forming benzene, toluene, and xylenes from paraffin wax under conditions like those resulting in the formation of the same compounds from petroleum cracking.

709. — The re cracking of cracked oils produced from petroleum. *Jour. Phys. Chem.*, vol. 20, October, 1916, pp. 597-620. An investigation to determine advisability of using distillate from cracked petroleum for further cracking and to ascertain yields of either gasoline or aromatics which might be obtained. It was found that cracked oil is adapted for production of aromatics, though giving smaller yields than petroleum, and not being as well adapted for production of gasoline; and that carbon formation is greater when cracked oil is re cracked than when petroleum is cracked.

710. — Time factor in the formation of aromatic hydrocarbons from a paraffin-base oil. *Met. and Chem. Eng.*, vol. 15, Sept. 1, 1918, pp. 245-250. In the formation of benzene, toluene, and xylene by cracking a gas oil from Pennsylvania crude at a constant temperature of 700° C., pressure of 150 lbs., and rates of flow of 12 to 36 gals. per hour, a study was made of the effect of rate of flow on the per cent of recovered oil and the specific gravity of the recovered oil; on the formation of benzene, toluene, and xylene in the recovered oil; on their formation on the basis of oil used; on the distillate to 170° C. and the sp. gr. of the distillate; on the sp. gr. of the benzene, toluene, and xylene cuts at 15.5° C.; and on the distillate from the recovered oil above 170° C., as shown by the distillation cuts and the specific gravity.

711. EGLOFF, GUSTAV, TWOMEY, T. J., AND MOORE, R. J. The cracking of paraffin-base oils. The time factor and temperature factor under pressure. *Met. and Chem. Eng.*, vol. 15, Nov. 1, 1918, pp. 523-529. Describes experiments to determine the type of oils which lend themselves most readily to the formation of aromatic hydrocarbons, gasoline, and unsaturated hydrocarbons, and the percentage yield of these products. A gas oil from Pennsylvania crude was cracked at temperatures from 400 to 750° C., constant pressure of 150 pounds and varying rates of flow. Paraffin-base oils yielded uniformly smaller percentages of these products than naphthene oils.

712. — The effect of temperature and the time factor in the formation of gasoline in the gas phase at constant pressure. *Jour. Ind. and Eng. Chem.*, vol. 8, December, 1916, pp. 1102-1106. Describes procedure and results of experiments with Pennsylvania crude, which was subjected, after the gasoline had been removed, to varying temperatures (600, 650 and 700° C.), constant pressure of 150 pounds, and varying rates of flow to form gasoline from the residue.

713. ——— The thermal and pressure decomposition of a naphthene base oil in the gas phase. *Met. and Chem. Eng.*, vol. 15, Oct. 1, 1916, pp. 387-392. Describes the effect of temperature and pressure on a naphthene base oil in the formation of gasoline, unsaturated hydrocarbons, and aromatic hydrocarbons. Two oils gave widely differing percentages of gasoline, etc., under the same conditions of temperature and pressure, showing the importance of the starting oil, when maximum yields of certain types are desired.
714. FISCHER, FRANZ. Über die Gewinnung flüssiger Kohlenwasserstoffe durch Einwirkung von Aluminiumchlorid auf Naphthalin unter Druck (Obtaining liquid hydrocarbons by the action of aluminum chloride on naphthalene under pressure). *Ber. deut. Chem. Gesell.*, Bd. 49, February, 1916, pp. 252-259; *Chem. Abs.*, vol. 10, Apr. 20, 1916, p. 1039. Naphthalene was treated with 4 per cent of its weight of $AlCl_3$ in an autoclave for a short time at about 330° , about 40 per cent being converted into liquid hydrocarbons, and the remainder into pitch and coke. The oil obtained may be used as an illuminant in a burner with a powerful air-draught, such as are designed for Russian oils.
715. FISCHER, FRANZ, AND NIGGEMANN, HERMANN. Formation of toluene by the action of anhydrous aluminium chloride on xylene and benzene. *Ber. deut. Chem. Gesell.*, Bd. 49, 1916, pp. 1475-1482; *Jour. Soc. Chem. Ind.*, vol. 35, Oct. 16, 1916, p. 1006. About 12 per cent of toluene, together with a certain proportion of benzene and of higher homologues of xylene may be obtained by boiling xylene with from 2 to 4 per cent of $AlCl_3$ for two hours. Traces of toluene are also obtained by the action of $AlCl_3$ on benzene.
716. PETROLEUM REVIEW. Aromatisation of petroleum. Vol. 35, Oct. 7, 1916, p. 285. Reviews a Russian article in "Nefannole Dielo," by I. Gutt, on the pyrogenisation products of petroleum, such as ethylene, butadiene, isoprene, etc., and gives their characteristics.
717. RITTMAN, W. F., AND EGLOFF, GUSTAV. Thermal reactions in the vapor phase of various coal-tar oils and distillates. *Met. and Chem. Eng.*, vol. 14, Jan. 1, 1916, pp. 15-18. Gives results of experiments made to test the utility of various low-grade coal-tar oils and distillates as original material for the production of toluene and benzene.
718. RITTMAN, W. F., AND TWOMEY, T. J. Equilibrium relations among aromatic hydrocarbons produced by cracking petroleum. *Jour. Ind. and Eng. Chem.*, vol. 8, January, 1916, pp. 20-22. Experiments with a gas oil, distillate from Pennsylvania crude, showed that there are definite relations among the percentages of aromatic compounds formed, these percentages being fixed by the degree of cracking. Gives a table of percentages by weight of each hydrocarbon constituent in eight runs.
719. TIKHVINSKI, M. M. The aromatization of petroleum. *Petroleum Rev.*, vol. 35, Nov. 11, 1916, p. 386; Nov. 18, p. 418; Nov. 25, p. 433; Dec. 2, p. 454. Gives classification of petroleum as to their aromatic hydrocarbon content and explanation of the value of aromatization. Reviews early patents for the pyrogenetic decomposition of petroleum. Describes apparatus required by modern methods and their procedure. Predicts that aromatization will supply material for dyes, explosives, and pharmaceutical preparations.
720. ZANETTI, J. E. Thermal decomposition of the propane-butane fraction from natural-gas condensate. *Jour. Ind. and Eng. Chem.*, vol. 8, August, 1916, pp. 674-678. Investigation of composition of cracked gases with respect to "unsaturated" and hydrogen formation; the amount of tar formed

and its composition; the composition of the unsaturated hydrocarbons; and the influence of catalyzers.

721. ZANETTI, J. E., AND LESLIE, E. H. The thermal decomposition of the ethane-propane fraction from natural gas condensate. *Jour. Ind. and Eng. Chem.*, vol. 8, September, 1916, pp. 777-779. A study of a fraction that is used mainly for welding and lighting; follows the same lines of investigation as given in a former paper. (See No. 720.)
See also Nos. 672, 724.

ELEMENTARY ANALYSES.

SULPHUR.

722. SCHEIBLER, HELMUTH. Chemical constituents of bituminous tar-oil rich in sulphur (Ichthyol oils). *Ber. deut. chem. Gesell.*, Bd. 49, 1916, pp. 2595-2600.

ANALYTICAL NUMBERS (IODINE, BROMINE, SAPONIFICATION, ACETYL, SULPHURIC ACID, ABSORPTION, ETC.).

723. RADCLIFFE, L. G., AND POLYCHRONIS, C. The iodine absorption and tendency to sludge formation of some hydrocarbon oils. *Jour. Soc. Chem. Ind.*, vol. 35, March 31, 1916, pp. 340-343. Tabulates results of experiments using different reagents, different lengths of time, and different temperatures. Discusses relation between percentage of iodine absorbed and percentage of sludge deposited by an oil, and gives table showing this relation.
See also Nos. 736, 767.

HYDROCARBONS, HYDROCARBON DERIVATIVES.

724. BROOKS, B. T., AND HUMPHREY, I. W. The presence of benzene homologs in the high boiling distillates of petroleum. *Jour. Am. Chem. Soc.*, vol. 38, February, 1916, pp. 393-400. Experiments with heavy oils, paraffin wax and synthetic phenyl paraffin for the identification of the higher benzene homologs. Benzene, toluene, and *m*-xylene were found among the products from the cracking of heavy petroleum oils by distillation up to 420° and 100 lb. pressure and by heating with anhydrous AlCl_3 up to 300°. Commercial paraffin wax did not yield these products under the conditions named, but synthetic phenyl paraffin yielded benzene and toluene.
725. SCHREYER, B., AND KRAGEN, S. Ueber Oxydation von Erdölprodukten (On the oxidation of petroleum products). *Petroleum Ztschr.*, Jahrg. 11, Mar. 1, 1916, pp. 521-522; *Ztschr. angew. Chem.*, Jahrg. 29, 1916, Ref., p. 204. Different petroleum fractions, when oxidized with air in the presence of powdered dry sodium hydroxide and mercury, yielded from 1 to 1½ per cent of naphthenic acids, which were viscous liquids, having the characteristic odor; and red and green in color. Other oxidation products were in the form of yellow viscous oil with a pleasant odor.

OXYGEN COMPOUNDS.

PETROLEUM ACIDS AND ACID CONTENT.

726. VON KOZICKI, G., AND VON PILAT, S. Zur Kenntnis der Naphthensäuren (Naphthenic acids). *Petroleum Ztsch.*, Jahrg. 11, Jan. 5, 1916, pp. 310-316; *Ztschr. angew. Chem.*, Jahrg. 29, 1916, Ref., p. 175; reviewed in *Jour. Soc. Chem. Ind.*, vol. 35, May 15, 1916, p. 526. Describes experiments in which crude naphthenic acids (sp. gr. 0.9403 at 15° C.) from a Gallician petroleum

distillate were purified by conversion into potassium salts and extraction with petroleum spirit, then methylated and the methyl esters fractionated. By saponification of the various fractions naphthenic acids from $C_7H_{14}CO_2H$ up to $C_{24}H_{48}CO_2H$ were isolated. Experiments proved that the naphthenic acids are carboxylic acids.

See also No. 670.

HALOGEN COMPOUNDS.

727. BEDFORD, C. W. The production of the lower chlorides of methane from natural gas. *Jour. Ind. and Eng. Chem.*, vol. 8, December, 1916, pp. 1090-1094. Investigation in chlorination of the methane available in natural gas with a view to transforming it into chloroform instead of carbon tetrachloride. Reviews former work on this subject, describes experiments, and states conclusions.

727a. FICHTER, F., AND GLAUZENSTEIN, LUPU. (Electrochemical chlorination of benzene and toluene). *Ber. deut. chem. Gesell.*, Bd. 49, 1916, pp. 2473-2487. *Jour. Soc. Chem. Ind.*, vol. 36, Feb. 28, 1917, p. 207. *Chem. Abs.*, vol. 4, Oct. 10, 1917, pp. 2667-2668. Glacial acetic acid used to form a homogeneous solution with the hydrocarbon, making a better electrolyte.

REDUCED HYDROCARBONS, HYDROGENATION, AND CATALYSIS.

728. HAMBURGER, L. The hydrogenation of oils. *Chem. Weekblad, Jahrg. 13*, 1916, pp. 2-13; *Chem. Abs.*, vol. 10, Mar. 20, 1916, p. 826. Gives results of a study of the influence of temperature, pressure, divisibility of the catalyst, and the kind of oil (impurities) on the hydrogenation process.

729. KELBER, C. Die katalytische Hydrogenisation organischer Verbindungen mit unedlen Metallen bei Zimmertemperatur (The catalytic hydrogenation of organic compounds by means of base metals at ordinary temperatures). *Ber. deut. Chem. Gesell.*, Bd. 49, January, 1916, pp. 55-63; *Jour. Soc. Chem. Ind.*, vol. 35, Mar. 31, 1916, p. 382. Nickel salt is precipitated in presence of a suitable carrier, and then reduced at 450° C. The catalyst produced has an activity greater than that of nickel reduced at a much lower temperature.

730. PICKET, AIMÉ, AND LERCZYNSKA, I. Action du chlorure d'aluminium sur le pétrole. *Bull. Soc. chim.*, t. 19, September, 1916, pp. 328-334. Gives experiments to determine the effect of $AlCl_3$ on the higher fractions of petroleum from different localities. Fractions resembling "natural benzine" and natural asphalt were obtained.

See also No. 700.

ASH CONTENT, see No. 670.

MISCELLANEOUS AND SPECIFIC TESTS.

731. FRIEDMANN, WALTER. Einwirkung von Schwefel auf Kohlenwasserstoffe unter Druck (Action of sulphur on hydrocarbons under pressure). *Petroleum Ztschr.*, Jahrg. 11, Sept. 20, 1916, pp. 1290-1302. Gives results of experiments with n-pentane, n-hexane, and n-octane.

732. ——— Einwirkung von Schwefel auf Naphthene unter Druck (Action of sulphur on naphthenes under pressure). *Petroleum Ztschr.*, Jahrg. 11, July 5, 1916, pp. 973-982. Describes compounds isolated when cyclohexane, methyl-cyclohexane, and octonaphthene were heated with sulphur.

733. ——— Einwirkung von Schwefel auf Octane unter Druck (Action of sulphur on octane under pressure). *Ber. Deut. Chem. Gesell.*, Bd. 49, 1916,

pp. 1344-1352. Describes compounds isolated when normal octane is heated in a sealed tube with sulphur.

734. ——— Einwirkung von Schwefel auf Octylene unter Druck (Action of sulphur on octylene under pressure). *Ber. deut. Chem. Gesell.*, Bd. 49, 1916, pp. 1551-1554; *Chem. Zentr.*, 1916, II, pp. 391-392. Various compounds were isolated.

735. ——— Einwirkung von Schwefel auf Olefine unter Druck (Action of sulphur on olefine under pressure). *Petroleum Ztschr.*, Jahrg. 11, 1916, pp. 696-697; *Ztschr. angew. Chem.*, Jahrg. 29, 1916, Ref., p. 358; *Chem. Zentr.*, 1916, I, p. 1285. Describes compounds isolated from hexylene octylene, and hexadecylene when heated with sulphur.

736. WATERS, C. E. Data on the oxidation of automobile cylinder oils. *Tech. Paper 73*, U. S. Bureau of Standards, 1916, 20 pp. Gives rate of oxidation of three oils when exposed to sunlight and air, and determinations of the increase in weight, the increase in acidity and carbonization values, as well as changes in the Maumene and iodine numbers and in the demulsibility. Also gives changes in the carbonization values of the three oils and of eight others, when heated for different lengths of time at a given temperature, and for the same time at different temperatures. Conclusion reached was that the carbonization value is independent of the flash and fire points and of the evaporation loss on heating.

See also Nos. 759, 1303.

PHYSIOLOGICAL PROPERTIES.

737. BROOKS, B. T. The nature of pharmaceutical naphthene oil (liquid petrolatum). *Jour. Am. Med. Assoc.*, vol. 66, Jan. 1, 1916, pp. 24-26. Discusses the chemical character, properties, mode of manufacturing, and testing of oils of this class.

738. OILDOM. "Petromortis." Vol. 6, Aug., 1916, pp. 376-380. Describes asphyxiation from exhaust gases from automobile engines. Article is reprinted from the "Travelers standard."

ANALYTICAL METHODS; DETERMINATION OF PHYSICAL AND CHEMICAL PROPERTIES; APPARATUS AND PROCEDURE.

739. AMERICAN GAS INSTITUTE. Gas chemists handbook. New York, 1916, 345 pp. Contains standard methods of analysis of gas oil, methods of analysis of paint vehicles, including petroleum, and tests for lubricating oils.

740. CHÉNEVEAU, C. Balance pour la détermination rapide des densités de corps liquides et solides (Balance for the rapid determination of the densities of liquid and solid bodies). *Rev. gén. Sci.*, t. 27, Aug. 15-30, 1916, p. 494. Paper read before the Société Française de Physique, June 6, 1916. Describes principle and use of apparatus.

741. DANIELS, FARRINGTON. An adiabatic calorimeter. *Jour. Am. Chem. Soc.*, vol. 38, Aug., 1916, pp. 1473-1480. Gives description of a modification of the Richards type, and discusses its advantages, chief of which is the elimination of cooling corrections, thereby excluding errors from precision work and saving time in commercial work.

742. MENDELSON, SIMON. Modified flash point apparatus. *Chemist-Analyst*, October, 1916, pp. 10-11. Describes apparatus and enumerates its advantages.

743. METALLURGICAL AND CHEMICAL ENGINEERING. An industrial and laboratory gas calorimeter. Vol. 14, May 15, 1916, p. 610. Describes calorimeter

- of Junker type in which heat from flame of either a liquid or gas fuel is introduced into a stream of water and calorific value of fuel is calculated from amount of water, of gas, and rise in temperature of water.
744. OILDOM. A rational basis for motor gasoline specifications. Vol. 6, July, 1916, pp. 334, 336. Abstract from paper read before American Petroleum Society, San Francisco, Oct. 25, 1915, by P. W. Prutzman. Gives tests to be used in checking specifications.
745. REEVE, C. S., AND PRITCHARD, F. P. A new penetration needle for use in testing bituminous materials. Jour. Agr. Research, vol. 5, Mar. 13, 1916, pp. 1121-1126. An easily reproduced needle is described which might be used as a standard, as there is no recognized established standard with which new needles may be compared.
746. RICHARDSON, CLIFFORD. The formolite reaction of Nastukoff as applied to oil residuals and natural asphalts. Jour. Ind. and Eng. Chem., vol. 8, April, 1916, pp. 319-321; discussion, p. 663. Gives results of attempts to apply the reaction between heavy oils and formaldehyde and sulphuric acid, as worked out by Nastukoff, to asphalts as a means of characterizing and differentiating them.
747. SEVERIN, E. Methodical analysis of petroleum. Petroleum Rev., vol. 35, Sept. 16, 1916, p. 226; Sept. 23, p. 247. Extracts from a Roumanian article. Outlines a method of analysis as worked out with Campina (Roumanian) petroleum, which consists (1) of treatment with sulphuric acid for separating the aromatic hydrocarbons and olefines, the ethylenes and non-saturated naphthenes, and (2) of treatment with a nitro-mixture for isolating the benzenic homologues in a solid state, thus allowing them to separate from the paraffins and saturated naphthenes.
748. UNITED STATES BUREAU OF STANDARDS. The testing of hydrometers. Circular 16, 1916, rev. ed., 16 pp. Presents specifications for hydrometers. Describes tests performed by the Bureau, and gives directions for submitting apparatus for test, and fees for testing.
- See also Nos. 632, 634, 636, 637, 640-642, 651, 654, 656, 658, 659, 666, 671-675, 678, 681, 682, 684, 685, 689, 691, 693, 698, 699, 702, 710-713, 723, 759, 763, 767, 771, 772, 921, 931.
- POWER AND EFFICIENCY TESTS, see Nos. 638, 977, 982, 989, 1032, 1248.

PATENTS.

749. BAUER, H. F. Viscosity testing apparatus. U. S. patent 1,190,085, July 4, 1916.
750. BERG, JAMES, AND BERG, G. Hydrometer. U. S. patent 1,179,996, Apr. 18, 1916.
751. BLICHFELDT, S. H. Production of emulsions. U. S. patent 1,192,492, July 25, 1916.
752. BRINDLE, R. G. Testing device (specific gravity). U. S. patent 1,178,902, Apr. 11, 1916.
753. BURRELL, G. A. Gas-analyzing apparatus. U. S. patent 1,176,199, Mar. 21, 1916.
754. DODGE, H. P. Specific-gravity measuring means. U. S. patent 1,189,431, July 4, 1916.
755. LORENZ, C. O. Viscosometer. U. S. patent 1,187,000, June 13, 1916.
756. MOELLER, M. E. Hydrometer. U. S. patent 1,177,128, Mar. 28, 1916.
757. SMITH, H. F. Method of determining the total available heat of gaseous fuel. U. S. patent 1,189,300, July 4, 1916.

SPECIFICATIONS FOR PURCHASES, ETC.

- 758.** HEYNE, H. R. Petroleum products and their requirements. *Fuel Oil Jour.*, vol. 7, January, 1916, pp. 39-41. Gives important points in general specifications stated for gasoline, kerosene, gas oil, fuel oil, lubricating oil and signal oil.

See also Nos. 10, 266, 688, 690, 744, 777.

VARIOUS SPECIES AND FRACTIONS OF BITUMENS AND PETROLEUMS.

GASEOUS PRODUCTS, INCLUDING NATURAL GAS.

- 759.** BURRELL, G. A., AND JONES, G. W. Methods of testing natural gas for gasoline content. Tech. Paper 87 U. S. Bureau of Mines, 1916, 26 pp. Deals especially with the applicability of the compression and condensation process and the absorption process for recovering gasoline from natural gas.
- 760.** BURRELL, G. A., AND ROBERTSON, I. W. The compressibility of natural gas at high pressures. Tech. Paper 131, U. S. Bureau of Mines, 1916, 11 pp. Results of investigations of the natural gas at Pittsburgh, Pa. Calls attention to the fact that the pressure-volume relation of Boyle's law does not hold for natural gas under high pressure, and points out possible errors in measuring natural gas.
- 761.** ——— Vapor pressures of various compounds at low temperatures. Tech. Paper 142, U. S. Bureau of Mines, 1916, 32 pp. Describes experiments using ethylene and ethane, propane, propylene and butane, acetylene, ammonia, sulphur dioxide, and nitrous oxide.
- 762.** DVORKOVITZ, PAUL. The gasification of coal and liquid hydrocarbons. *Petroleum Rev.*, vol. 35, Dec. 16, 1916, pp. 485-486. Reviews results of experiments carried on twenty-three years ago by the author, and recently corroborated by the investigations of Pictet, Ramseyer and Kaiser (*see* No. 764). After concluding that liquid hydrocarbons exist in coal, the author devised a method of gasifying coal so as to avoid the destruction of the volatile matters in it, and thus obtained illuminating gas equal to 31,000 candles per ton of coal, 8 gallons of paraffin, 100 lb. of pitch, and 4 gallons of by-products of great value.
- 763.** EARHART, R. F., AND WYER, S. S. Deviation of natural gas from Boyle's law. *Trans. Am. Soc. Mech. Eng.*, vol. 38, 1916, pp. 285-308; discussion, pp. 308-329. Gives results of an investigation made by measuring natural gas samples from various parts of the United States. The apparatus is described and illustrated, the order of conducting the tests are given, and the results recorded in tables and curves. (*See also* No. 689.)
- 764.** PICTET, AIMÉ, RAMSEYER, L., AND KAISER, O. Sur quelques hydrocarbures contenus dans la houille (On some hydrocarbons contained in coal). *Compt. rend.*, t. 163, Oct. 9, 1916, pp. 358-361. Gives results of experiments to ascertain whether hydrocarbons are contained in coal or whether they are pyrogenetic decomposition products. Concludes that coal is a solid hydrocarbon material impregnated with a liquid which is closely allied to petroleum. (*See also* No. 762.)

See also Nos. 203, 204, 257, 480, 689, 690, 753, 757, 921.

VOLATILE FRACTIONS, INCLUDING MOTOR OILS, GASOLINES, NAPHTHAS, BENZINES.

765. BURRELL, G. A. Gasoline and how to use it. Boston, 1916, 281 pp. Gives general information on the nature of gasoline, methods of its production, and use as motor fuel.
766. STRACHE, H. Das Benzin, seine Gewinnung, Beschaffenheit, und Lagerung (Benzine, its production, properties and storage). Petroleum Ztschr., Jahrg. 11, Mar. 1, 1916, pp. 522-527; Mar. 15, 1916, pp. 569-575.
- See also* Nos. 10, 744, 758, 977, 989, 1253.

LUBRICATING, TRANSFORMER, AND SWITCH OILS.

767. INSTITUTION OF ELECTRICAL ENGINEERS. Insulating oils. Jour., vol. 54, 1916, pp. 497-504. Report on properties and methods of testing transformer and switch oils, giving detailed methods of investigation for the following characteristics: tendency to sludge, loss by evaporation, flash point, viscosity, acidity or alkalinity and iodine value, specific gravity, cold test, moisture absorption, dielectric test, specific resistance, thermal transference, specific heat.
768. PECK, E. P. Testing and filtering transformer oil. Elec. World, vol. 67, June 17, 1916, pp. 1413-1414. Discusses methods of taking samples, use of special test box, preparation of filter papers, and operation of filter press.
- See also* Nos. 641, 649, 651, 653, 657, 659, 663, 665, 667-671, 739, 758, 931, 1017.

PARAFFIN, OZOKERITE, CERESIN, VASELINE, ETC.

769. MARCUSSEON, J. The composition of the solid hydrocarbons of petroleum, paraffin and ceresin. Mitt. K. Materialprüf., Jahrg. 33, 1916, pp. 415-426; Chem. Zentr., 1916, I, p. 1285. Describes investigations relating to the detection and determination of paraffin and ceresin.
770. PETROLEUM ZEITSCHRIFT. Paraffin aus Erdöl (Paraffin from petroleum). Jahrg. 11, Sept. 6, 1916, p. 1244. Abstract of Russian article discussing the properties and uses of paraffin and its mixture with other waxes.
- See also* Nos. 107, 128, 129, 131, 646.

ASPHALT, TARS, ETC.

771. FITCH, T. A. Practical testing of asphalt and road oil. West Eng. vol. 7, February, 1916, pp. 53-54, abstract. Describes the penetration test, the detection of carbonates, separation of water and sediment, test for light oil constituents, tests after asphalt is combined with road materials, and determination of proportions of asphalt and other materials.
772. GARY, M. Examination of asphalt. Mitt. K. Materialprüf., Jahrg. 33, 1916, pp. 210-220; Jour. Soc. Chem. Ind., vol. 85, May 15, 1916, pp. 525-526. Describes Richardson's penetrometer and the "ductilometer." Tests show that differences in degrees of softness increased with rise of temperature from 15° to 25°. Asphalts and asphaltic material containing less than 96 per cent of bitumen can not be directly tested for ductility.
773. GRAEFFE, E. Zur Unterscheidung von Natur- und Kunst-Asphalt (Distinguishing between natural and artificial asphalt). Ztschr. angew. Chem. Jahrg. 29, I, Jan. 25, 1916, pp. 21-25. Discusses formation of natural asphalts and manufacture of oil asphalts. Describes test for sulphur. Re-

actions given by different kinds of asphalt are recorded. Gives table of sulphur content of various kinds of asphalt, pitches, etc.

774. LAXTON, J. L. The maintenance of sheet pavements. Jour. Eng. Club, St. Louis, vol. 1; September-October, 1916, pp. 346-355. Includes general description of asphalt and laboratory tests. Describes process of oiling pavements as dust preventive and for waterproofing.
775. MARCUSSON, J. Der chemische Aufbau der Naturasphalte (The chemical structure of natural asphalts). Ztschr. angew. Chem., Jahrg. 29, I, 1916, pp. 346-351; Jour. Soc. Chem. Ind., vol. 35, Nov. 15, 1916, p. 1099. Gives methods for making the following determinations: free acids, acid anhydrides, asphaltenes, unaltered oil, and petroleum resins; also gives table of results and discusses the formation and composition of asphalt constituents.
776. ——— Distinction between natural and artificial asphalts. Les Matières Grasses, t. 9, 1916, pp. 4490-4491; Chem. Abs., vol. 10, Nov. 10, 1916, p. 2797. Studies the acid number and saponification number of natural and artificial asphalts.
777. ——— Standards for products of the asphalt industry. Mitt. K. Materialprüf., Jahrg. 34, 1916, 40-55; Jour. Soc. Chem. Ind., vol. 35, Nov. 15, 1916, pp. 1099-1100. Gives results of investigations and methods of analysis worked out by the author and others, natural and artificial asphalts may be distinguished, mixtures identified, etc. Reviews briefly specifications adopted by various cities and private consumers for asphalt products, and gives standards for the manufacture of roofing felt.
778. RICHARDSON, CLIFFORD. Importance of the relation of solid surfaces and liquid films in some types of engineering construction. Good Roads, vol. 12, Dec. 2, 1916, pp. 235-236, abstract. Paper read before the Western Society of Engineers, Nov. 20, 1916. Discusses in detail the effect of colloidal clay in bitumens used in pavements.
779. ——— The merits of natural asphalt roads. Good Roads, new series, vol. 11, Jan. 1, 1916, pp. 15-16. Munic. Jour., vol. 40, Apr. 6, 1916, pp. 483-484. Abstracts of paper read before Road Congress at Worcester, Mass. Gives properties of natural asphalt, explains its use in road making, and describes methods of construction.

See also Nos. 16, 235, 632, 684-691, 746, 935, 936.

SHALES, MISCELLANEOUS SOLID BITUMENS, LAMPBLACK, AND COKE.

780. HELM, W. H. Peat as a source of fuel oil. Jour. Roy. Soc. Arts, vol. 64, Jan. 7, 1916, pp. 150-151. Gives a short discussion of the value and possibilities of peat oil as fuel. Emphasizes the absence of sulphur as a distinct advantage, particularly in naval engines.
- See also Nos. 122, 124, 260-263, 298.

REFINING AND REFINERIES.

PROCESSES AND PRACTICES.

781. ASHWORTH, A. A. Economy in refining. Paper read before Western Petroleum Refiners' Association, Kansas City, Mo., Nov. 16, 1916. Published in pamphlet, "Petroleum Refining," by Western Petroleum Refiners' Association, Kansas City, Mo., pp. 31-35. Discusses loss of gasoline content of crude by lax methods of refining, the extravagant use of fuel, and use of properly designed condensers. Suggests saving of gases that escape condensation. Mentions the economical operation of refineries in Europe.
782. CAMPBELL, ANDREW. The refining of petroleum. Jour. Inst. Petroleum Tech., vol. 2, June, 1916, pp. 274-295; discussion, pp. 295-302. Gives a sketch of process and plant for "straight" refining from a refiner's point of view. Describes process for distillation, paraffin extraction and refining, and chemical treatment, giving methods and apparatus for each.
783. GRANT, E. E. Fuel situation. Gas Engine, vol. 18, Sept., 1916, pp. 446-451. Discusses various gasoline processes as a means of increasing the yield of gasoline, and the adaptation of kerosene as fuel.
784. KNOCH, F. E. Oil refining. Oildom, vol. 6, Feb., 1916, pp. 63-65, 67. Discusses principles of refining and the properties of hydrocarbons.
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BITUMEN FUELS FOR INTERNAL-COMBUSTION ENGINES.

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See No. 982.

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- 1259.** OIL, PAINT AND DRUG REPORTER. New and cheaper fuel for automobiles found. Vol. 89, May 22, 1916, p. 40-I. Describes briefly a gasoline-kerosene combination treated chemically. Less of this mixture than of gasoline is used for same mileage.
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See also No. 780.

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- 1262.** GLICK, B. N. Alcohol—the fuel of the future. Automobile, vol. 35, Nov. 30, 1916, pp. 932-934. Considers possibilities in the production of alcohol and benzine suitable for fuel, emphasizing the enormous supply of wood waste as a source of alcohol.
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NOTE.—In this index the names of the authors are printed in heavy type; the word "oil" used by itself signifies petroleum, but the word "gas" by itself does not signify natural gas; "oil fields," "gas fields," "oil statistics," "gas statistics," etc., refer to petroleum and natural gas.

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RELIEF MAP OF IDAHO.

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

A PRELIMINARY REPORT ON THE MINING DISTRICTS OF IDAHO

BY

THOMAS VARLEY, CLARENCE A. WRIGHT, EDGAR K. SOPER
AND DOUGLAS C. LIVINGSTON

(In cooperation with the University of Idaho)



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A PRELIMINARY REPORT ON THE MINING DISTRICTS OF IDAHO.

By THOMAS VARLEY, CLARENCE A. WRIGHT, EDGAR K. SOPER, and
DOUGLAS C. LIVINGSTON.

INTRODUCTION.

In 1917 the Federal Bureau of Mines and the University of Idaho arranged to cooperate in an investigation looking to the improvement of mining and milling methods in the mining districts of the State of Idaho, with an especial view to the wider development of the mineral deposits and greater efficiency in the treatment of the low-grade ores of the State. This work has been made possible largely through the generosity and active assistance of the mine operators, especially certain companies in the Coeur d'Alene region.

As the first step in the work under the cooperative agreement it was decided to gather all data possible on the various mining districts throughout the State, both active and abandoned, in order to ascertain their potential possibilities, especial attention being paid to methods of metallurgical treatment and to the solution of the many metallurgical problems in order to effect a greater commercial saving.

With this plan in view, field work was begun in the latter part of May, 1917, and was continued during the summer. E. K. Soper, formerly professor of mining, University of Idaho, and now dean of the mining department of Oregon Agricultural College, Corvallis, Oreg., visited the mining districts in central and southwestern Idaho and also some of those in the northern part of the State. D. C. Livingston, professor of geology at the University of Idaho, Moscow, Idaho, also visited some of the mining districts in central Idaho during the summer; in addition, much valuable information he had gathered on former trips to many other districts is included in this report. Credit is also due Mr. Livingston for the maps covering the State, as well as the bibliography at the end of each chapter. Thomas Varley, superintendent of the Seattle mining experiment station of the Bureau of Mines, spent a short time in the field, principally in the mining districts in central and northern Idaho, and made a brief visit to the southwestern districts

with Mr. Soper. The field work of Mr. C. A. Wright, metallurgical engineer of the Bureau of Mines, in direct charge of the cooperative work, was chiefly in the Coeur d'Alene region. Mr. Wright visited nearly all of the mining districts in the region and devoted most of his time to studying the milling methods.

The results of the investigation are set forth in this bulletin. The bulletin aims to give the localities of the various mining districts, and the nature of the present operations and those that have been carried on in the past. The geology is discussed only in a general way, the descriptions being intended more especially to bring out the types of ore deposits and the character of the ores, a knowledge of which is essential in determining the proper treatment of the ores. The writers do not wish to imply that all districts mentioned in this bulletin were visited during the summer of 1917, for a great deal of the material has been gathered from other reports, especially from publications of the United States Geological Survey. However, it is hoped that this report will be of help to those who are interested in mining in the State of Idaho.

The plan is to continue the field work and subsequently publish the results of the investigations in much more detail, with greater emphasis given the metallurgical treatment of the ores and the problems involved.

ACKNOWLEDGMENTS.

The bibliography was compiled by the late Dr. A. C. Stewart, who was professor of geology at the University of Idaho from 1911 to 1914, and has been completed and brought up to date by Mr. D. C. Livingston.

The writers take pleasure in acknowledging their indebtedness to all mine owners and mining companies for furnishing much information, for extending many courtesies and special privileges, and for giving assistance in every way possible.

Acknowledgment is made here to George W. Evans, coal-mining engineer of the Seattle mining experiment station of the Bureau of Mines, for the chapter on the Teton coal deposits in the southeastern part of the State.

The writers are also indebted to Francis A. Thomson, dean of the school of mines at the University of Idaho, for helpful suggestions, and to Robert N. Bell, State mine inspector of Idaho, for facts, figures, and historical data pertaining to the mining industry of the State.

ORE-TREATMENT PROBLEMS.

The treatment of the Idaho ores involves several problems, but those that seem to be of greatest importance are (1) the concentration of the complex lead-zinc-iron ores and (2) the treatment of gold-silver ores that are not amenable to straight amalgamation.

The first group of ores, namely, the lead-zinc-iron ores, are well represented in the Coeur d'Alene region, Shoshone County, and in the Wood River district, Blaine County. Under this group might be included, however, the deposits of the Lakeview and Blacktail districts in Bonner County and those of the Clarke Fork district in Bannock County, as well as such lead-zinc-iron and lead-zinc-copper ores found in other parts of the State as are difficultly separated by the usual methods of gravity concentration.

Where the lead-zinc-iron ores are as finely disseminated as the ores found in the mines of the Pine Creek, Nine Mile, and other districts of the Coeur d'Alene region, to make clean products of lead and zinc by gravity methods is next to impossible. It has been found in examining material finer than 200 mesh under the microscope that some of the lead and zinc particles were still mechanically combined. Although at most mills a large percentage of both the lead and the zinc content is recovered in the concentrates from the jigs, fine grinding is essential to liberate the minerals and make a clean separation, with finely disseminated ores of this character. Owing to this fact, considerable amounts of zinc in lead concentrates, and no small amount of lead in zinc concentrates, is lost by the present methods of concentration. The question arises, therefore, as to whether a closer separation of the minerals is commercially feasible. Possible improvements in methods and equipment to effect a closer concentration are discussed in detail under mill practice in the Coeur d'Alene region (pp. 24 to 30), such as finer grinding, larger flotation plants, fine grinding and differential flotation combined, preliminary roasting followed by flotation, or some hydrometallurgical process.

To avoid radical changes in the mills and in the local methods it would seem advisable, if possible, to effect a better separation by differential flotation, with whatever changes in the existing methods of treatment this might necessitate. It is along these lines, therefore, that the Bureau of Mines, in cooperation with the University of Idaho and mine operators of the State, has been experimenting and will continue to put especial stress.

Under the second group would come the gold ores of the Boise Basin region, in Boise County, the Atlanta district, in Elmore County, the Silver City and De Lamar districts, in Owyhee County, the Seafoam and Greyhound districts, in Custer County, and the central Idaho district, which is mainly in Idaho County.

The Boise Basin region, comprising the Quartzburg, Grimes Pass, Elk Horn, Idaho City, and other local districts, has many mines. In this region a large tonnage of gold and silver ore in quartz or altered granite gangue, said to average between \$7 and \$10 per ton, is available. The future of the region depends largely upon the successful solution of the serious milling and treatment problems which now confront the operators. The ores worked in the earlier days in this region were principally free-milling gold ores, and all the mills were stamp mills of the California type, with straight amalgamation. With depth the ore gradually became more base, and table concentration and cyanidation were added to the milling process. Stamp milling will now only save about 50 per cent of the values, and much of the gold remaining in the ore is lost because of inadequate milling facilities. Thus far only the concentrates have been subjected to cyanidation. The ore is still crushed in the original stamp mills, and most of the mills are out of date and are making poor recoveries.

The history of the treatment of gold ores in the Silver City and de Lamar districts, Owyhee County, has been similar to that of those in the Boise Basin region. In the upper levels of the mines the ore was chiefly oxidized vein material and included much material that was free milling. Rich silver-chloride ore and lead-silver ore supplied much of the production from certain properties. As greater depth was attained the ore became more base and could no longer be profitably amalgamated. This necessitated changes and alterations in the mills, especially the addition of cyanide plants, and during the later years of activity in these districts practically all of the ore was cyanided. The costs of mining and treatment were always high in the Silver City district, largely because of the high cost of transportation and supplies. This resulted in a large quantity of ore of milling grade, partly oxidized ore, being left in some of the old stopes and on the old mine dumps. Much of this material could probably be reworked at a profit by proper milling methods. Considerable development work is now under way in the district, tunnels being driven to intersect the ore bodies at depths of 500 to 1,000 feet below the old workings. If ore in payable quantity is encountered at these greater depths there will be urgent need for metallurgical advice regarding proper methods of treatment. The problems involved will probably be confined to proper methods of grinding and the best methods of cyanidation.

In the Seafoam and Greyhound districts the ores comprise several distinct types, the principal types being gold-bearing pyrite in quartz veins, associated with considerable arsenopyrite and antimony sulphides, and complex ores containing mixtures of chalcopyrite, argentiferous galena, and auriferous pyrite, associated with arsenical and antimonial sulphides. The hauling of concentrates from this district would not be practicable under present transportation facilities, but experiments in cyaniding these ores would seem desirable, because the district contains some high-grade ore which could be mined at a profit if the haulage and transportation costs were eliminated.

From these general statements it can be readily seen that the chief treatment problem for the complex and low-grade gold-silver ores is to determine the best methods of milling, followed by cyanidation, or cyaniding direct, according to the metal content and character of the ore, in order to effect a high recovery and to produce bullion, thus eliminating the costs of haulage and transportation as much as possible. Many prospects and properties throughout the State await further development of the ore bodies and the additional capital for making changes in the mills necessitated by the increase of sulphides in the ores, which are no longer free milling. If the treatment problems of these ores were solved many old properties might be reopened and the production of gold be increased.

There are other ore-dressing problems connected with the ores in this State that need attention, such as are encountered in the concentration of lead, zinc, and gold ores and also of molybdenite, tungsten, and manganese ores, but the main purpose of solving the many problems is to effect a higher recovery of the valuable mineral on a commercial scale, whether the ores are complex or low grade.

BRIEF HISTORICAL REVIEW OF MINING IN IDAHO.

EARLY DISCOVERIES OF GOLD.*

Gold is reported to have been found on the Pend Oreille River in 1852, but not in sufficient quantity to attract much attention, and placer mining was carried on only in a small way in northern Idaho until 1860. In that year Capt. E. D. Pierce discovered gold on Orofino Creek, a tributary of the Clearwater River, which resulted in a stampede into that locality in the summer of 1861 and the establishment of Pierce City. Prospectors spread over the country drained by the Salmon and Clearwater Rivers and Elk City, Florence, Warrens, Dixie, and other camps were established at about the same time, with Lewiston as the principal distributing point for this mining region.

In addition to the miners, the same type of lawless element was attracted to these gold fields as frequented Skagway, Juneau, and Dawson during the Klondike rush, and a period of lawlessness ensued which rivaled California in the fifties and has never been adequately described. The troubles of the prospectors were further complicated by the fact that the Nez Perce Indians claimed the land upon which most of the gold discoveries were made. The Indians were peaceable, owing largely to the training they had received at the Spaulding and Coeur d'Alene missions, otherwise the history of this mining boom might have been written in blood, as the Nez Perces were a powerful tribe.

Boise Basin, which was the largest and most important of the placer-mining districts of Idaho, was discovered in 1862 by Moses Splawn, who had previously mined gold at both Elk City and Florence. Splawn learned of Boise Basin from a Bannock Indian, who described its location and told of finding there the same yellow metal as the miners were washing out of the gravel at Florence and Elk City. Splawn outfitted a party in the spring of 1862 to search for the Basin. These men reached Boise Basin in August of the same year, and found gold at a place where the town of Centerville now stands. They were attacked by Indians, and a member of the party George Grimes, was killed near the creek that still bears his name. The rest of the party returned to Walla Walla and persuaded 50 men to return with them to the Basin, which they reached in October and found free from Indians. This party was followed by many others

* McConnell, W. J. History of Idaho. 1913. p. 56.

and by November the towns of Placerville, Centerville, Idaho City, and Pioneerville had been located and partly built, and by the following spring were rather important places. The following year witnessed the rush of miners to Boise Basin with the heterogeneous crowd of camp followers always accompanying such an influx, particularly in territorial days.

Placer gold was discovered at Silver City in 1862, a short time prior to the finding of gold at Boise Basin, and one of the discoverers, Jordan, was killed by the Indians in 1864. In 1863 silver ore was discovered on War Eagle Mountain by one of a party of miners from the Boise Basin who were hunting down Indian horse thieves, and the opening of the important gold-silver camps of Silver City dates from that time. The gold-quartz veins of Rocky Bar and Atlanta were discovered and worked about the same time. Considerable prospecting went on in Lemhi County shortly after this time, which resulted in the discovery of several placer and many quartz mines. It was not, however, until the late seventies and early eighties that silver-lead mining became important in southern Idaho, at Wood River, Clayton, Bay Horse, and Nicholia. In 1863 there were about 16,000 people in Boise Basin and it was the center from which prospectors spread over the mountainous region south of the Salmon River. The market for farm produce created by this mining population induced many settlers to take up farms in the Boise and Payette Valleys.

EARLY POLITICAL HISTORY OF IDAHO.

Previous to 1863 Idaho had been included in the Territory of Washington, but the discovery of gold and the influx of people that followed created so much difficulty in the administration of the laws from Olympia that Idaho was organized into a separate Territory.

The bill creating the Territory of Idaho was signed by the President on March 3, 1863, and the territory embraced under that name included the present States of Montana, Wyoming, and Idaho, with an area of over 300,000 square miles. On March 17, 1864, the Territory of Montana was organized from the northeastern part of Idaho and in June, 1863, the Territory of Wyoming was formed from the southeastern part, leaving Idaho in its present form, with Lewiston as the temporary capital. The capital was permanently established at Boise by the act of the second session of Territorial legislature in 1864. Idaho became a State by act of Congress in 1890.

DISCOVERY OF COEUR D'ALENE REGION.*

In 1879 Prichard Creek was discovered by a party that had traveled northward from the Mullan road. In 1882 placer gold was dis-

* Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey, Prof. Paper 62, 1908, p. 78.

covered on Prichard Creek by Gillett, a member of the same party. Prichard also located a number of claims in 1883; in 1884 there was an influx of miners and the towns of Eagle and Murray were founded. Many of the claims were very rich; the gold was coarse with some unusually large nuggets. Also, some quartz veins, such as the Golden Chest, were located.

About this time interest was aroused in the lead-silver deposits on the South Fork of the Coeur d'Alene River. Wallace was founded in 1884 by Col. W. R. Wallace, who had a store on the flat where the town now stands. Many of the important mines on Burke and Mullan Canyons, such as the Hecla, Tiger, Gold Hunter, Morning, Frisco, and Black Bear, were located during 1883 and 1884. In 1885 the Bunker Hill mine and the Sullivan mine were opened. The large bodies of ore opened in these mines, and in the mines farther up the river, caused a rush into the district in 1886 which resulted in a shift in population from Murray to Wardner and other South Fork points.

In those early days transportation was the chief problem, as the ore from the Bunker Hill and Sullivan mines had to be hauled to Mission by wagons and then taken on boats to the outlet of the lake and shipped to Helena, Mont. In 1887 a narrow-gage railroad was built from Mission to Wardner, and in 1890 both the Northern Pacific and the Oregon-Washington railroads reached the district from the east and the west, respectively.

In 1892 labor troubles compelled several of the mines to close, and some violent scenes were enacted. The buildings of the Gem mine were blown up with dynamite. Order was restored by troops. Trouble broke out again in 1899 when the office and mill of the Bunker Hill and Sullivan mine were dynamited and several men were shot. Troops were ordered into the district and martial law was proclaimed, the mines remaining closed for several months.

In 1898 the county seat was moved from Murray to Wallace, as the population at the former place had dwindled, owing to the exhaustion of the placer gold.

In 1901 the Hercules mine commenced shipment of rich lead-silver ore, the output being increased from year to year until in 1914 this mine was the banner producer of the district.

In recent years the important developments have been the opening up of the Nine Mile, Beaver Creek, and Pine Creek districts, and the discovery of rich zinc ore at the Interstate-Callahan mine, as well as the finding of big bodies of lead-silver ore at considerable depth in many of the older mines, such as the Bunker Hill and Sullivan, Hercules, Hecla, and Morning.

The erection of a smelter by the Day interests at Northport in 1916 to treat ores from the Hercules and Tamarack mines and another

smelter by the Bunker Hill & Sullivan Co. near Kellogg in 1917 marked a new era in the history of mining and ore treatment in this region.

The discovery of the lead-silver ores in Shoshone County shifted the center of mining activity from the southern part of the State to the northern. Another factor which had a tremendous effect upon mining in Blaine, Lemhi, and Custer Counties was the drop in the price of silver in the early eighties. Several small smelters were operating in this mountainous country in the eighties that were forced to close down at that time, and these counties have not yet regained their former condition of activity, although the building of the Gilmore and Pittsburg Railroads into Lemhi County has renewed mining in that particular section.

NEW ACTIVITIES.

The irrigation of vast tracts of desert land in the Snake River plains is resulting in a large increase in agricultural population in the southern part of the State, and in addition there is a big lumber industry in the timbered mountainous regions, particularly in the north, so that mining in Idaho, although a far larger industry now than it has ever been, is relatively less important than formerly. It must be remembered, however, that the State would have been years behind its present population and prosperous condition if it had not been for the discovery of gold in the Clearwater Mountains and Boise Basin, and the history of the State has been closely interwoven with the development of its mines.

MINING DISTRICTS OF IDAHO AND OUTPUT.

EXTENT OF MINERALIZATION.

Idaho contains one of the largest areas of mineralized territory in the United States. The great mountainous area (Plate I), 50,000 square miles in extent, that extends from the Snake River on the south to British Columbia (nearly the entire length of the State), is mineralized through almost its entire length. The ores in this belt include gold, silver, copper, lead, zinc, quicksilver, nickel, tungsten, and molybdenum. Among the valuable nonmetallic minerals found in Idaho are coal, phosphate rock, asbestos, tripoli, fire clay, and mica.

There are about 150 organized mining districts in the State in which various kinds of ores have been produced at one time or another. Many of these districts have been idle for years, whereas others have enjoyed long periods of continuous activity and are still productive. Few of the idle districts, except the old placer diggings, have become so because of the total exhaustion of the ore, most of them are idle because of the exhaustion of the high grade, bonanza, or free-milling ore near the surface, and because the lack of transportation facilities renders unprofitable the mining of the remaining lower grade ore. Plate II shows the distribution of the mining districts.

Notwithstanding the wide distribution of the ore deposits, by far the greater part of the metal production comes from the Coeur d'Alene district, Shoshone County, in the northern part of the State. The total gross value of the metals produced in Idaho in 1916 was \$48,000,000, of which \$11,500,000 was paid in dividends. More than 90 per cent of the total production came from the Coeur d'Alene regions.

IDAHO MINE OUTPUT IN 1917.*

The value of the gold, silver, copper, lead, and zinc mined in Idaho in 1917, according to the statement of C. N. Gerry, of the United States Geological Survey, Department of the Interior, was about \$54,000,000, an increase of more than \$5,000,000 over the value in 1916. There were decreases in all the five metals except lead, in which there was a slight increase. Idaho was freer from labor

* Statement by U. S. Geol. Survey.

troubles than the neighboring States, particularly Montana and Washington. The average prices of silver, copper, and lead were unusually good, and every effort was made to ship larger quantities of ore, particularly lead ore. The new lead smelter of the Bunker Hill and Sullivan, near Kellogg, began operations in July, and the lead plant at Northport, Wash., was active during the entire year, treating principally Idaho silver-lead ores. The output of crude ore and concentrate, both lead and zinc, increased from 527,266 tons in 1916 to about 572,000 tons in 1917.

There was a decrease in the gold output from \$1,115,810 in 1916 to about \$715,000 in 1917, due principally to the fact that the large dredge at Idaho City, Boise County, was idle. Shipments of gold bullion were made from the Marshall Lake district of Idaho County, where the Sherman & Corporal property has become a large gold producer. The lead ore produced contains a small amount of gold, and the copper ore, especially that of the Alder Creek district in Custer County, and the Richmond mine in Shoshone County contains considerable gold. A dredge that had been moved from Alaska to Prichard Creek, near Murray, in Shoshone County, was ready for operation in December.

The production of silver was about 11,773,000 ounces, slightly less than that in 1916, when the State produced 12,300,873 ounces. The price, however, was so much better that the value of the output increased from \$8,093,974 to about \$9,536,000. The Coeur d'Alene region contributed most of the silver, and the largest producers were the Hercules, Bunker Hill & Sullivan, Morning, Hecla, Caledonia, Tamarack & Custer, Greenhill-Cleveland, Gold Hunter, Stewart, Consolidated Interstate Callahan, and Last Chance. In Boundary County considerable silver is contained in concentrates shipped from the Idaho Continental property. In Lemhi County also silver is produced from lead ore. Increased output was made by the Morning, Hecla, and Bunker Hill properties.

The mine output of copper decreased from 8,478,281 pounds in 1916 to about 6,753,000 pounds in 1917. The value decreased from \$2,085,657 to about \$1,971,000. The properties at Mackay, in Custer County, and principally the mine of the Empire Copper Co. contributed most of the copper output. Shipments of copper ore were made from the Richmond mine, where the new tramway to Adair was operated. The Caledonia mine at Wardner produces ore containing copper as well as silver and lead. Toward the end of the year the plant of the National Copper Co. was again operated and made shipments of concentrates in November and December. Other shipments were also made from the Horst Powell property north of Kellogg.

The output of lead increased from 375,081,781 pounds in 1916 to about 383,000,000 pounds in 1917, and the value increased from \$25,883,643 to about \$34,595,000. The principal producers in the Coeur d'Alene region were the Bunker Hill & Sullivan, Hercules, the Federal properties (especially the Morning mine), the Hecla, Greenhill-Cleveland, Caledonia, Success, Gold Hunter, and Consolidated Interstate Callahan. The Jack Waite property became a shipper of lead ore, and the Hypotheek increased its lead output. Having acquired the Frisco mill, the Tamarack & Custer Consolidated made shipments of lead concentrates in the last half of the year. In Lemhi County, the Pittsburgh-Idaho, Latest Out, and Gilmore made shipments of lead ore; in Boundary County, the Idaho Continental; at Arco, the Wilbert Mining Co.; and near Mackay, the Copper Queen and Homestake. Ore production in Lemhi County was less than in 1916.

As the price of zinc decreased considerably toward the end of the year, the average was only about 9 cents a pound. The State output decreased from 86,505,219 pounds in 1916 to about 80,000,000 pounds of recoverable zinc in 1917. The value was approximately \$7,336,000. The output of the main producer, the Consolidated Interstate Callahan, decreased about 20 per cent. This mine averaged over 5,000 tons of ore and concentrate per month, part of which was a lead product. Shipments of zinc ore or concentrate were also made from the Morning, Success, Rex, Highland Surprise, Constitution, Greenhill-Cleveland, Frisco, Black Hawk, Marsh, Douglas, Ray Jefferson, and Nabob. Most of the zinc came from Shoshone County, but the North Star mine, near Hailey, in Blaine County, belonging to the Federal Co., became a producer of zinc concentrate during the year. A great part of the zinc product was sent to the electrolytic plant at Great Falls, Mont., and part of the ore, such as that from the Douglas mine, was concentrated after being shipped.

The dividends from Idaho mining for eleven months amounted to nearly \$6,000,000. The principal contributors were the Hecla, Bunker Hill & Sullivan, Caledonia, Hercules, Consolidated Interstate Callahan, Pittsburgh-Idaho, Wilbert, Empire Copper, Big Creek Leasing Co., Douglas, Richmond, Black Hawk Leasing Co., and Tamarack & Custer.

THE NORTHERN COUNTIES.

BOUNDARY, BONNER, KOOTENAI, AND BENEWAH.

The northern area comprises Boundary, Bonner, Kootenai, and Benewah Counties, and embraces the greater part of the lake region of northern Idaho. The topography is mainly rough (see Plate I), with elevations ranging from 1,870 feet on the Kootenai River to more than 7,000 feet in the Selkirk and Cabinet Mountains.

These counties* are underlain principally by the Belt series of sediments, which have been intruded by granite in several places, notably in the neighborhood of Priest Lake. Benewah County has been partly covered by basalt, which also appears in isolated areas in some of the other counties. Ancient gneisses occur at Post Falls in Kootenai County. The mineralization is, in the main, similar in the different districts in these counties.

BOUNDARY COUNTY.

PRIEST LAKE DISTRICT.

The Priest Lake district has a somewhat ill-defined boundary, part of it being in Boundary and part in Bonner County. According to the General Land Office map the region extending from the Continental mine in Boundary County to Priest River station in Bonner County is embraced in this district.

The most important part of the district at the present time is the area in the northwest corner of Boundary County, near the Canadian boundary, known locally as the Port Hill district.

There is only one producing mine in the district, the Idaho-Continental, which is reached by a good wagon road from Port Hill, a distance of 26 miles. This property is one of the most important producers of lead outside of the Coeur d'Alene region. In addition to this mine there are a number of promising prospects, with good surface showings, upon which little or no development work has been done.

At the Idaho-Continental mine the ore, galena associated with pyrite in a quartzite gangue, occurs as a replacement in fissures or shear zones in sedimentary rocks. The ore deposit shows considerable

* Goode, R. U., Survey of the boundary line between Idaho and Montana from the international boundary to the crest of the Bitterroot Mountains: U. S. Geol. Survey Bull 170, 1900, 65 pp.

similarity, both in geologic occurrence and general characteristics, to those worked at the mines of the Coeur d'Alene region. The mine-run ore averages about 10 to 12 per cent lead, with half an ounce of silver to 1 per cent of lead. A little chalcopyrite is also present. The concentrates contain only 1 to 2 per cent zinc, so that treatment of the ore mined thus far does not involve any problem in the separation of lead and zinc.

There seems to be a considerable tonnage of this kind of ore available, as the vein is persistent, with widths of 10 to 20 feet. The lowest adit tunnel gives backs of 350 feet, with known ore extending below this level, as proved by driving winzes.

The ore is mined by the shrinkage system, at a cost of \$2.80 per ton, the expense of timber being almost entirely eliminated. Some excellent crude ore is shipped. The cost of hauling the high-grade ore and concentrates to Port Hill is \$8 per ton.

The ore is milled in a concentrator having a capacity of about 250 tons a day. The milling consists of crushing with Blake crusher and rolls, followed by jigging; then recrushing with fine rolls, followed by concentration on tables and vanners. Flotation was not used during the summer of 1917, but its installation at an early date was contemplated by the company. The mill recovery is reported to be about 70 per cent, and will undoubtedly be higher when a flotation unit is installed. The concentrate averages about 60 per cent lead and 25 ounces of silver per ton.

The treatment problems involved are apparently the avoidance of sliming of the galena in crushing and the recovery of the slimed galena by flotation. The 26-mile haul by wagon renders the cost of operating in this district higher than is usual in the Coeur d'Alenes, but this has been partly offset by a cheap method of mining.

Besides the lead-silver deposits in the northern part of the district, copper occurs near Priest Lake.*

MOYIE-YAAK DISTRICT.

The Moyie-Yaak district is situated in the northeastern part of the county on the drainage area of the Moyie River.

There are several prospects in the district showing lead, gold, and copper, but no producing mines.

BONNER COUNTY.

LAKE VIEW DISTRICT.

The Lake View district is a part of the Pend Oreille region which lies along the shores of Pend Oreille Lake. The district is reached

* Courtis, W. M., Priest Lake mining district, Idaho: Eng. and Min. Jour., vol. 82, Nov. 10, 1906, p. 866.

by the Spokane and Inland Empire Railroad to Bayview, on Pend Oreille Lake, and thence by boat to Lakeview post office. Most of the mining properties are located about 5 miles southeast of Lakeview post office and are reached by wagon road.

The ore occurs in fault fissures with sheared and crushed wall rock and much gangue, in which are bands and stringers of quartz, the gangue consisting mainly of the crushed wall rock. The ore shoots are 3 to 5 feet wide. The ore in general is a complex mixture of galena, sphalerite, and pyrite, with silver-bearing sulpharsenides and sulphantimonides, frequently some tetrahedrite, and is difficult to treat. There are no mills in the district, but some high-grade ore has been shipped. Some of the ore is reported to have run as high as 1,000 ounces of silver to the ton. A number of the properties have a considerable tonnage of milling ore opened, and profitable exploitation would seem to depend upon the proper milling treatment, as the transportation conditions could be made favorable.

Seemingly, investigation of the ores of this district would be worth while, as its present state of inertia is largely due to an unsolved problem of treating a somewhat complex ore.

The mines of the district are the Webber, Keep Cool, Rainbow, Conjecture, Spider and Venezuela, but none of them were operating during the summer of 1917.

BLACKTAIL DISTRICT.

The Blacktail district is on the west shore of Lake Pend Oreille. The mines of this district are about a mile from the Blacktail boat landing and about 6 miles from Sagel station, on the main line of the Northern Pacific Railway, from which point there is a good wagon road.

The ores consist of silver-bearing galena, associated with tetrahedrite, argentite, sphalerite, pyrite, and chalcopyrite, and are very similar in occurrence and also in mineral content to those of the Lakeview district. The gangue is chiefly siderite with a considerable amount of crushed wall rock.

The principal mine of the district is the Keystone or Armstead. The vein is a fissure vein, which cuts the slates at a slight angle. The average width is 2 to 4 feet, but the vein pinches to less than 2 feet in some places and widens to more than 6 feet in other places. The ore is galena, with tetrahedrite, chalcopyrite, argentite, and native silver, in a quartz and siderite gangue. An ore shoot on this vein with a length of 1,000 feet has been developed to a depth of 500 feet. The average width of this shoot is 3 to 4 feet, and the ore is supposed to run 30 to 50 ounces in silver to the ton. The mine is developed by tunnels. A tunnel was driven to intersect the vein at a depth of 1,800 feet below the surface. The latest reports from the

property are that this crosscut has reached the vein, and the ore is of good grade and several feet in width. The completion of this tunnel has been watched with considerable interest, as it is the deepest one in the district and the development of a considerable body of ore by it should stimulate mining at adjoining properties.

The vein is mined by first stripping about 18 inches of waste from the hanging wall side and breaking the ore. The waste is used for filling, and the ore is dumped into chutes placed 25 feet apart. An occasional stull is used to hold up the hanging wall. The method is simple, effective, and cheap, the cost being about \$2.80 per ton for ore delivered at the mouth of the tunnel.

There is no mill on the property, and only high-grade ore has been shipped in the past. The company is contemplating the erection of a mill as there is plenty of water available and electric power can be had from Sandpoint, about 12 miles distant.

The treatment problem involves the making of a clean lead-silver concentrate and elimination of pyrite and siderite. Some of the ore may slime badly on account of the presence of brittle tetrahedrite, and flotation may be necessary.

There are other undeveloped prospects with similar characteristics in the district whose immediate future depends largely upon the deeper developments in the Armstead mine.

CLARK FORK DISTRICT.

The Clark Fork district lies in the neighborhood of the town of Clark Fork on the main line of the Northern Pacific Railway. The district is recorded in the General Land Office at Boise as the Cœur d'Alene district, but the local name is used here. Its boundaries are indeterminate.

The Lawrence mine* is the only one having a mill, and practically all the properties in the district are still in the prospect stage.

At the Lawrence mine the ore is silver-bearing galena in quartzitic slate. The vein is very irregular, but several large shoots of high-grade ore have been found. The ground between the ore shoots is poor and systematic development is needed to insure a regular supply of ore. Several parallel ledges are reported to occur on the property, but only one had been opened in 1917 and that to a comparatively shallow depth. The mill, which has a capacity of 50 tons a day, is equipped with crushers, rolls, jigs, and tables, and makes a high-grade lead concentrate carrying 11 to 15 ounces of silver to the ton. There is no flotation equipment.

* Flagg, A. L., Lawrence mine and mill in Kootenai County, Idaho: *Min. and Eng. World*, vol. 38, Feb. 15, 1913, pp. 340.

Other partly developed properties in the district are the Copper Giant, Hidden Treasure, Lucky Strike, and Clarinda. The ore deposit at the first carries copper in a quartz vein; those at the Lucky Strike and Hidden Treasure are silver-lead deposits, and that at the Clarinda carries lead, silver, and copper.

The most pressing need of this district is systematic prospecting and development of the known ore bodies, rather than the solution of milling problems, which necessarily follows rather than precedes the development of ore bodies.

The limestone that outcrops on the shore of Lake Pend Oreille at Squaw Bay near Lakeview* should be mentioned, as it has been used as an ingredient for making cement in Spokane and should be considered as a mineral asset of importance to Bonner County.

HOPE DISTRICT.

The eastern part of the Pend Oreille district is locally known as the Hope district, according to the General Land Office. The district apparently adjoins the Clark Fork district on the east and is situated near the town of Hope on the Northern Pacific Railway.

This district has not been developed beyond the prospect stage. A small amount of work done on some of the prospects has exposed some fairly good ore carrying lead-silver and copper minerals. Some of the best known prospects in the district are the Morning Star, Margarite, El Paso, Rebecca, Black Bear, Big Five, and Park River.

KOOTENAI COUNTY.

According to the records of the General Land Office in Boise, there are three districts in Kootenai County in which mining claims have been patented. None of these districts have producing mines, and very little is known about the ore occurrences. The districts include an unorganized district near Rathdrum and the Wolf Lodge and Medimont districts in the eastern part of the country.

BENEWAH COUNTY.

The only mining district in Benewah County in which claims have been patented is the Camas Cove or Tyson Creek district. This district is in the southeastern corner of the county and lies along Tyson Creek, a tributary of the St. Maries River, about 3 miles from Fernwood on the Elk River Branch of the Chicago, Milwaukee & St. Paul Railroad. It adjoins the Hoodoo district in Latah County.

* Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana, with notes on the economic geology, by D. F. MacDonald. 1909, pp. 7-91.

A low-grade gold-bearing quartz vein in schist has given rise to placer gravel at the head of a depression which in some previous period was a small lake. The gravel, which consists of angular fragments, immediately overlies the ancient lake bed. One company is hydraulicking this gravel with water brought from the other side of the St. Maries River, and there are several other operators in the neighborhood.

The quartz vein from which the placer gold has been derived would appear to be too low-grade for profitable exploration, although ore shoots of value may be found.

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SHOSHONE COUNTY.

Shoshone County produces most of the lead-silver ore mined in Idaho, as it contains the Coeur d'Alene region, which ranks as the second great lead-producing region in the United States. In addition, the region is producing a considerable amount of zinc, as well as some copper and antimony, and a little placer gold. The gold output is being considerably increased by dredging on Pritchard Creek near Murray.

DISTRICTS IN THE COEUR D'ALENE REGION.

The Coeur d'Alene mining region embraces the following districts: Beaver, Evolution, Hunter, Lelande, Murray, Pine Creek, Placer Center, Shoshone, St. Regis, Summit, and Yreka.

BEAVER DISTRICT.

The Beaver district lies on the drainage of Beaver Creek, one of the principal tributaries of the North Fork of the Coeur d'Alene River.

A spur from the Murray branch of the Oregon Short Line Railroad has recently been built into the district, and most of the properties are now within easy reach of railroad transportation.

The ores are in fissure veins, and shear zones in slate. Most of the ore occurs as seams, bands, or lenses in the sheared slate, the walls of the ore body being often difficult to determine. In some places the ore is brecciated, and in other places the ore minerals form the cementing material of a slate breccia, or crushed vein matter.

The ore is chiefly sphalerite, with subordinate amounts of silver-bearing galena, associated with much pyrite. The sphalerite and galena frequently occur in fine-grained massive mixtures, very difficult to separate in the mill. The gangue is principally sheared slate, with quartz and calcite.

The principal mines of the district are the Ray-Jefferson, Idora, Tuscumbia, and Red Monarch.

EVOLUTION DISTRICT.

The Evolution district is situated between Kellogg and Wallace and lies on both sides of the South Fork of the Coeur d'Alene River.

The district contains no producing mines of importance, although considerable prospect work is being done. On the north side of the

river on Moon Gulch there are several prospects, one of which, the Idaho-Knickerbocker, has shipped ore recently.

HUNTER (MULLAN) DISTRICT.

The Hunter (Mullan) district^a is contiguous to the town of Mullan and contains some of the most important lead-silver mines in the Coeur d'Alene region. Considerable zinc occurs with the lead, but the latter is the principal metal. The lead-silver ore occurs in fault fissures cutting quartzitic rocks. The district also has two copper deposits, that at the Snowstorm mine, which has been worked out, and that at the National mine, which is under development and in active operation.

The Morning and the Gold Hunter mines are the two most important lead-silver properties in the district. The ore at the Morning mine is complex, as considerable sphalerite is associated with the galena in a gangue of siderite with some barite and quartz. Pyrite and pyrrhotite also occur. The Morning mine has large ore reserves, and undoubtedly has a long life ahead of it. The ore at the Gold Hunter mine is somewhat similar to that at the Morning mine, with possibly more barite present. The present workings are in one of the upper formations of the Belt series and as the vein is persistent, the future of the mine, when the workings are extended into the Revett and Burke formations, should be bright.

The Snowstorm deposit consisted of an impregnation of copper carbonates carrying silver in the beds of the Revett formation. The ore was cut off by a fault and the mine has been idle for some time.

The deposit at the National mine is very similar to that at the Snowstorm mine, except that the copper occurs chiefly as disseminated sulphides—chalcopyrite with a little chalcocite and silver-bearing tetrahedrite—and is in a highly silicified bed of the Revett formation. The exact tenor of the ore is not known.

LELANDE (BURKE) DISTRICT.

The Lelande (Burke) district^b is situated near Burke. The ore is chiefly lead-silver ore, in veins in quartzitic rocks.

Some of the greatest lead ore deposits of the Coeur d'Alene region are in this district. It contains the Hercules, Hecla, Greenhill-Cleveland (practically exhausted), Frisco, and Marsh mines, as well as many other properties in different stages of development.

^a For geology see Calkins, F. C., and Jones, E. L., *Economy geology of the region around Mullan, Idaho, and Salt Lake, Mont.*: U. S. Geol. Survey Bull. 540, 1914, pp. 167-211. Ransome, F. L., and Calkins, F. C., *The geology and ore deposits of the Coeur d'Alene district, Idaho*: U. S. Geol. Survey, Prof. Paper 62, 1908, pp. 164-171.

^b For geology see Ransome, F. L., and Calkins, F. C., work cited, pp. 172-182.

Thus far zinc has not been encountered in any quantity, although lead-zinc ore is now being mined from the Oronogo vein at the Hecla mine. It is interesting to note that a body of zinc ore was encountered in the Hercules during the early years of the mine's history, and the first flotation plant ever installed in the region was for treating this zinc ore.

The district has undoubtedly a long period of production ahead of it. More zinc will probably be encountered as greater depth is attained.

MURRAY (EAGLE) DISTRICT.

The Murray, or Eagle, district^a is in the vicinity of Murray, the oldest town in the region, and lies principally to the northeast of that town. The boundaries between this district and the Summit district are very indistinct. The Murray district was formerly an important one for its gold production, and yielded millions of dollars in the eighties. Recently a dredge was built to work over some of the old ground, and also ground which has never been previously washed and is now successfully dredging below the town of Murray.

In addition to the placer gravels, gold-bearing quartz veins also occur, usually as blanket deposits in slates. The deposit at the Golden Chest mine is one of these. The ore at this mine also contains tungsten as scheelite, and in 1916 an attempt was made to treat this ore in the remodelled mill, but apparently without success, as the mill was shut down after being run for a short time.

PINE CREEK DISTRICT.

The Pine Creek district^b lies in the drainage area of Pine Creek, west of Kellogg, and is reached by a recently constructed spur line from the Wallace branch of the Oregon Short Line Railroad. The district is one of the newest producers in the region, although the deposits have been known for many years.

The ores resemble closely those of the Beaver district and are complex mixtures of sphalerite, argentiferous galena, and pyrite, in a gangue of sheared slate with quartz and some calcite. The recent activity in the district is due largely to improved methods of treating these complex ores. The principal mines are the Constitution, Highland Surprise, Douglas, Nabob, Northern Light, Hypotheek, and Amy-Matchless. The district has undoubtedly a promising future, as there is evidently a large tonnage of this type of ore available, which will become more profitable as treatment processes are still further improved.

^a Ransome, F. L., and Calkins, F. C., work cited, pp. 90, 141.

^b For geology see Ransome, F. L., and Calkins, F. C., work cited, p. 189.

PLACER CENTER (WALLACE) DISTRICT.

The Placer Center (Wallace) district* embraces the mines of Nine Mile Creek, extending from Wallace to Sunset, and the surrounding territory. The ores contain more zinc than those of the Burke and Mullan districts, and usually consist of intimate mixtures of galena and sphalerite, with more or less pyrite, siderite, and magnetite.

Some ore from the Tamarack mine, that was examined in the geological laboratory of the University of Idaho, showed particles of galena as small as 1/1000 of an inch in diameter inclosed in sphalerite. In other places, shoots of clean galena and sphalerite are found, as at the Interstate-Callahan mine, where the ore in many parts of the mine is nearly pure sphalerite. The silver is associated with the galena, probably as argentite or tetrahedrite, and runs about one-half ounce to one per cent of lead.

The principal mines of the district include the Interstate-Callahan, Tamarack, Rex, Success, and Alameda.

SUMMIT DISTRICT.

The Summit district lies south of the Shoshone or Coeur d'Alene district, and includes part of the drainage of Granite Creek and Idaho Gulch. There are several prospects, but no producing mines.

YREKA (KELLOGG-WARDNER) DISTRICT.

The Yreka district is situated adjacent to the town of Kellogg-Wardner and contains the great Bunker Hill & Sullivan mine. The ores are chiefly silver-bearing galena ore, the oxidized parts of the veins being richer in silver than most of the Coeur d'Alene deposits. These ores are less complex and are easier to mill than the ores from most of the other lead-silver mines of the region, and contain very little zinc. The gangue is largely siderate. The ore deposits are of large size, insuring ample ore reserves for several years, and the building of the Bunker Hill & Sullivan smelter near Kellogg will be of material assistance to the district.

Besides the Bunker Hill & Sullivan mine, the Caledonia, Stewart, and Last Chance mines and several promising prospects are situated in this district.

OTHER DISTRICTS IN SHOSHONE COUNTY.

In Shoshone County mineralized areas outside of the Coeur d'Alene region are not very plentiful, but the following occur in the rugged, mountainous country lying south of the Coeur d'Alene River. The descriptions have been taken mainly from those of Pardee.^b

* For geologic relations see Ransome, F. L., and Calkins, F. C., Work cited, pp. 105-189.

^b Pardee, J. T., Geology and mineralization of the upper St. Joe River Basin, Idaho: U. S. Geol. Survey Bull. 470 f. 1911, pp. 39-61.

BALD MOUNTAIN (MONITOR) DISTRICT.

The Bald Mountain, or Monitor district,^a also known as the St. Regis district lies $5\frac{1}{2}$ miles west of Salt Lake, Mont. The ore bodies are veins in sedimentary rocks, and contain gold with sulphides of copper and iron in a gangue of siderite, calcite and quartz. Some of the more important properties are the Bald Mountain, Monitor, and Richmond mines.

BLACK PRINCE (EAST COEUR D'ALENE) DISTRICT.

The Black Prince district^b is situated on the main line of the Chicago, Milwaukee & St. Paul Railway, near the mouth of Black Prince Creek, on St. Joe River. The ore bodies are veins in the quartzite, and are very similar to those of the Bald Mountain district, although somewhat more irregular in occurrence. The more important prospects are the Copper Prince, Kelly, and Theriault.

SHOSHONE (COEUR D'ALENE) DISTRICT.

The Shoshone district lies east of Murray and extends to the Montana divide. The boundaries that separate this district from the Murray district on the west and from the Summit district on the south are not well defined.

The principal country rock is slate, although quartzite occurs, and considerable areas of granite or monzonite. Lead and zinc minerals occur^c in fissure veins in the slate, but there are no large producing mines in the district at this time, although several mines were operating in 1917. Among these might be mentioned the Terrible Edith mine, which was shipping high-grade lead ore, and the Giant Ledge mine on Granite Creek. At the latter mine, a body of disseminated galena and chalcopryrite extends along a fault fissure with granite forming one wall of the fissure. This disseminated material is 15 to 25 feet wide, and there seems to be a considerable tonnage exposed in the workings. The material is very low grade and both cheap mining and a well-designed mill will be needed to work it on a paying basis.

A similar type of ore is found on the "Lilly" property, on the west fork of Granite Gulch, except that the disseminated galena and chalcopryrite are in the granite instead of in the slate.

Other mines in the district are the Paragon, Chicago-London, Monarch, Black Horse, Bear Top, and Orofino.

^a Pardee, J. T., work cited, p. 55.

^b Pardee, J. T., work cited, pp. 57-58.

^c Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, 1908, pp. 190-191.

SLATE CREEK DISTRICT.

The Slate Creek district^a lies 15 miles south of Wallace on the drainage of the St. Joe River and is reached by trail from Wallace. The chief mineral, silver-gold bearing galena, is frequently disseminated through sedimentary rocks in small grains and veinlets, definite veins or fractures being scarce. The galena is associated with siderite and some sphalerite. The ore appears to be richer in gold and poorer in silver than the Coeur d'Alene region proper.

There are many prospects and no producing mines. The district is somewhat inaccessible.

SLIDEROCK MOUNTAIN DISTRICT.

The Sliderock Mountain district^b comprises the area near the heads of Floodwood and Fish Hook Creeks, in an inaccessible locality reached only by trails. Several prospects have been found in this district, but there has been little development and not much is known of the ores there.

ST. JOE DISTRICT.

The St. Joe district^c is situated about 25 miles west of Iron Mountain, Mont. Here placer gravel is found along the beds of streams tributary to the St. Joe River flowing from the Bitterroot Mountains. The district is best reached from the Montana side.

Several miles north of the placer district, on the southeast spur of Ward's Peak, is a group of claims lying mostly in Montana, but whether the deposits are in the St. Joe or in the Bald Mountain district is not evident. At the Ward mine, one of this group, is a mineralized zone 50 feet or more in width, which contains small amounts of chalcopryite, pyrite, and chalcocite in seams of quartz, calcite, and siderite. The whole mass is reported to assay about \$4 in gold.

MILLING PRACTICE IN THE COEUR D'ALENE REGION.

The mills in the districts of the Coeur d'Alene region vary in capacity from 100 to 1,500 tons in 24 hours. The methods of treatment of the ores are similar in that the ore is reduced by the usual types of gyratory and jaw crushers, rolls and tube mills, followed by jig and table concentration, while the slimes, in most mills are treated by flotation.

The lead and zinc ores are, as a rule, relatively high in mineral content, but are complex and often difficult to separate by the usual methods of gravity concentration. The mill recoveries claimed by

^a Pardee, J. T., work cited, pp. 60-61.

^b Pardee, J. T., work cited, p. 59.

^c Pardee, J. T., work cited, p. 54.

the different companies vary from 70 to 90 per cent. It is gratifying to note that most of the operators are constantly experimenting and endeavoring to increase the mineral recovery. This is clearly brought out by the fact that nearly all the operating companies were quick to realize the importance and possibilities of flotation to effect an additional saving of the valuable minerals, so that, with few exceptions, the flotation process is found in practically all the mills of this region.

HAND SORTING.

Hand sorting is practiced to a more or less extent at many of the mines and mills. Where hand sorting is employed and the mill is some distance from the mine, the sorting is usually done at the mine, although at a few places the ore is sorted at the mine and also at the mill. At some of the mills, when the ore is rather coarsely disseminated, both mineral and waste rock are sorted. The quantity of shipping ore thus sorted out, which is known as "crude ore" or "high grade," varies from a few per cent to as high as 60 per cent of the total tonnage of concentrates shipped.

The usual method of procedure in hand sorting is as follows: The oversize passes from the grizzly onto a wide conveyor belt, where the ore is washed with a spray of water, so the sorters can distinguish the mineral from the waste rock more readily. Men stationed on each side of the conveyor belt sort from the washed material either the mineral or the waste rock and drop it into shoots leading to the respective bins.

A paper* on hand sorting of mill feed was presented by R. S. Handy, mill superintendent of the Bunker & Sullivan Company, Kellogg, Idaho, at the meeting of the Columbia section of the American Institute of Mining Engineers, held at Kellogg, on November 17, 1917. This paper was most interesting and instructive, as well as the discussion that followed. Mr. Handy claimed that hand sorting of the mill feed is not necessary, and that it is cheaper, in fact, to treat the mill feed direct, without previous hand sorting, for the same amount of mineral saved and the price received for the product. The writer believes that Mr. Handy, who has made careful study of the treatment of the Bunker Hill ore, is correct in assuming that for this particular ore and under the conditions in the mill it is best to treat the mill feed direct without hand sorting. Whether, under different conditions, hand sorting is essential or not should be determined for each individual ore and is a matter well worthy of careful consideration.

* Handy, R. S., Hand sorting of mill feed: *Am. Inst. Min. Eng. Bull.*, April, 1918, pp. 961.

COARSE CRUSHING.

Instead of shipping the ore from the mines direct to the mill, several companies have a crushing plant at the mine where the ore is reduced to about four inches in diameter or less. This crushing is commonly effected by gyratory or Blake crushers. At other plants the mine run receives its first crushing at the mill.

Where hand sorting is practiced the ore passes over a grizzly or trommel screen with $1\frac{1}{4}$ to $1\frac{1}{2}$ inch openings. The undersize from the grizzly passes to storage bins; the oversize, after it has been sorted, is reduced in size by gyratory crushers or rolls, and joins the undersize of the original feed. The ore from the storage bins then passes to trommel screens of different size openings, the undersize being delivered to the various jigs and the oversize being returned to rolls which are in closed circuit with the screens.

COARSE SCREENING.

The various sizes to which the ore is graded by the screens varies in the different mills. In one mill where "bull jigs" are used, screens with perforations as large as 50 mm. in diameter are employed, whereas in other mills the perforations of the coarsest screens are usually not greater than 30 mm. in diameter. The trommel screens consist of two or three sections, each section having different size screen openings. The ore crushed for jig concentration is graded into five to seven different screen products ranging from 30 to $1\frac{1}{4}$ mm. in size, the screen openings differing somewhat at the various mills. The sizing of ore in this way for subsequent jig treatment is characteristic of the Coeur d'Alene region. It would be interesting to run several jiggling tests on the lead and zinc ores to ascertain whether some of the intermediate screen sizes could be eliminated, and whether the use of the jigs with larger cells would have any advantages.

JIGGING.

After the ore has been graded into its different sizes each screen product is treated separately on jigs. The jigs are commonly of the Hartz type and have three to five compartments; also, the Franz and Hancock types are used to some extent. The jig compartments are usually 18 by 30 inches in area, although in some of the mills larger compartments are used, especially in the "bull jigs."

As a rule the "bull jigs" receiving the coarsest material have two compartments and make only two products, a middling and a tailing. The middling is crushed through rolls and returned to the feed elevator for subsequent screen sizing and treatment over jigs, while the tailing is either discarded or reground for treatment over jigs and tables, the slimes, of course, being separated out for flotation

treatment. In one or two mills a final lead product is drawn from the first compartment of the "bull jigs" and the middling is taken from the second compartment only.

Where the ore contains both lead and zinc in commercial quantities, the lead concentrate is drawn off from the first cell of the jig, whereas the zinc product comes from the third cell, and also from the fourth cell in five-compartment jigs. The product from the second cell is a mixture of lead and zinc minerals and is generally joined with the middlings from the fourth and fifth compartments to be reground in a ball mill.

In jiggling ore containing lead only, final products are obtained from all compartments except the last one, from which a middling is drawn off. This middling is reground for subsequent treatment.

The jig tailings are handled differently at the various mills. In one mill all the tailings may be discarded without dewatering, whereas in another mill the tailings are dewatered before going to waste. Again, in other mills, only the tailings from the jigs treating coarse material are discarded, those from the jigs treating the finer material being reground and given further treatment; whereas in still other mills one will find that the tailings from all jigs are subjected to finer grinding and subsequent treatment.

From the many variations in jig treatment, it can be readily seen that each individual company adapts the method of treatment to the character of the ore. Although the method of treatment is similar, the flow sheet of each mill is different. These differences are even more noticeable in the treatment of the fine material on tables and by flotation.

TREATMENT OF FINE MATERIAL.

FINE CRUSHING.

For crushing the material such as middlings and tailings from jigs and tables to a size suitable for table concentration and for flotation, some type of pebble or ball mill is generally used. Both cylindrical and conical types are used in the mills of the district and both types are found in some mills. The ore in the ball mills is crushed wet, the mixture varying from about two parts ore to one part water to one part ore to two parts water. It is believed that the lower water content would result in more efficient crushing in the long run, depending of course upon the amount of slimes the mill man desires to produce. In general, more water is required for a granular product than for the production of a slime. Also, the proportion of water used has considerable effect on the capacity of the ball or tube mill.

However, each individual problem must be worked out to obtain the greatest crushing efficiency in the ball mills according to the conditions of operation and the kind of product desired.

The ball or tube mills, when used for fine crushing, are usually in closed circuit with classifiers, the oversize being returned to the tube mill while the overflow either passes to Dorr thickening tanks for flotation or to cones or hydraulic classifiers for subsequent treatment on tables. The sizes of cylindrical ball mills commonly used are 5 by 5, 5 by 10, and 6 by 14 feet; the conical type of Hardinge mills are usually 6 feet by 22 inches, although smaller and larger sizes are found in some of the mills.

TABLE CONCENTRATION.

As previously stated, the product from the tube mills or other fine grinding machines passes to classifiers where the slimes are separated from the coarse sands, which are returned to the grinding mills. This separation of the finer particles from the coarse is usually effected by the familiar types of classifiers, such as the Dorr, Akins, and the common type of drag classifier, also Callow cones are used in many of the mills.

For classification of sands for treatment on tables, the Callow cone, the Richards Janney classifier, or some other similar type of classifier is used. In some mills such screens as the Wood or Bunker Hill types are used for fine screening or for grading material 1.5 mm. or less in diameter. The slimes or overflows pass to Dorr thickening tanks, while the classified products of the fine sands are treated on tables. The material for the tables is generally 1.5-mm. to 150-mesh size.

In most of the mills lead and zinc products are separated on tables, but in the retreatment of middlings and tailings, one finds more or less variation in the flow sheets of the different mills. In some mills the middlings are retreated on separate tables, whereas in others the middlings are reground to be further treated by flotation. The tailings from tables are usually reground and treated by flotation, although in a few instances the tailings from the tables treating the relatively coarser sands are discarded as waste. The back water from the tables passes to the Dorr thickening tanks and flotation units.

A few mills treating lead ore are still equipped with vanners for the treatment of slimes. The tailings from the vanners, however, pass to flotation machines for final treatment, and it is a question whether the use of vanners together with flotation is the cheapest method. In all probability, however, the vanners were installed several years ago at the time the mills were built, before flotation was used in this country, and the operators have hesitated and even now dislike to discard all the vanners which are still in good working order and do not require much attention.

FLOTATION.

One of the noticeable features in the mills of the Coeur d'Alene region is that nearly every mill, small or large, has a flotation plant. The flow sheets of these flotation plants vary more or less, and at several plants two or three different types of flotation machines are to be found in the same mill.

As a rule the overflows and slimes, from the various steps in the mill process to be subsequently treated by flotation, pass to Dorr thickening tanks where the pulp is thickened to about 12 to 25 per cent solids. The thickened pulp is pre-agitated by air or mechanical means and is thoroughly mixed with the oil or flotative agent to bring the pulp into the best condition for flotation. From this point a roughing and cleaning system is generally followed to insure a high recovery and concentrates of acceptable grade, although in a few plants, where lead only is recovered, a final lead concentrate is obtained direct from the primary flotation cells without previous "roughing."

The different types of flotation machines used in the mills are of various makes and design. The three chief types are the pneumatic, mechanical-agitation, and subaeration machines. The pneumatic type is represented by the Callow machine; the mechanical-agitation types used most are the Mineral Separation, the Janney, and the Bunker Hill machines; and the subaeration type is represented by the Janney, the Ziegler, and the K & K machines. One or two other makes of machines used are local products; the principles of these might readily be included in some one of the above-mentioned machines. As subaeration is a combination of mechanical and air agitation, almost any mechanical type of machine can be converted into the subaeration type by simply adding the necessary air lines to the cells. The types of machines used throughout the Coeur d'Alene mills are about equally divided between the pneumatic and mechanical agitation.

The kind of oils used for floating the ores in the mills of this region are chiefly hardwood creosote, crude pine oil, and refined pine oil (usually steamed distilled); also other oils, such as fuel oil and coal-tar products, are used to some extent. Copper sulphate is used in a few mills together with oil, and other chemical reagents are being tested.

One or two plants are utilizing differential flotation for raising the lead and zinc sulphides separately, but the separation is not as clean as it might be. It is hoped that a good differential separation will be made possible by flotation, and at the same time give a commercially high recovery of both the lead and zinc.

The concentrates from the flotation machines are dewatered in settling tanks or Dorr thickeners and the product from these tanks passes to vacuum filters. The type of filters commonly used are the Oliver, Portland, Kelley, and American. The moisture content of the final product after filtration varies from about 8 to 13 per cent, whereas the flotation products that are not filtered, but are simply thickened in tanks, usually contain 15 to 25 per cent moisture. A reduction in moisture content to 3 or 4 per cent would be very desirable for plants having high freight charges, owing to the length of haul to the smelter. The commercial possibilities of effecting such a reduction in moisture content, whether by means of some type of drying furnace, such as the Lowden patented drier, or by use of a drier in combination with a vacuum filter, as suggested by Mr. R. S. Handy, would depend upon the cost of treatment and the saving in freight charges.

MILL PRODUCTS.

It has been stated that the chief metals produced from the mines of the Coeur d'Alene region are lead and zinc, with minor amounts of copper, silver, and antimony. Where the lead-zinc-iron minerals are as finely disseminated as in the ores mined in the Pine Creek, Nine Mile, and other districts, it is next to impossible to make clean products of lead and zinc by the usual gravity concentration methods. Although a good percentage of both lead and zinc concentrates is obtained from the jigs at most mills, fine grinding is essential to make a fairly clean separation of either mineral from the finely disseminated ores of this character. In fact, it has been found, in examining material finer than 200-mesh under the microscope, that some of the lead and zinc particles were still mechanically combined. The following examples will give some idea of the kind of ore treated and the products obtained by present methods of concentration.

Examples showing kind of ores treated and concentration products in mills of Coeur d'Alene region.

EXAMPLE 1.

Metal.	Feed to mill.	Zinc concentrates.
	<i>Per cent.</i>	<i>Per cent.</i>
Pb.....	11.4	15.4
Zn.....	16.9	31.4
Ag.....	3.6	5.0
Fe.....	6.1	2.3
Mn.....	.2	.3
S.....	14.0	21.1
Insoluble.....	50.0	18.6

* Ounces per ton.

Examples showing kind of ores treated and concentration products in mills of Coeur d'Alene region—Continued.

EXAMPLE 2 (AVERAGE FIGURES).

Metal.	Feed to mill.	Lead concentrates.	Zinc concentrates.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Pb.....	3.0	45.0	9.0
Zn.....	15.0	18.0	34.5
Fe.....	8.0	15.0	11.0

EXAMPLE 3 (AVERAGE FIGURES).

Metal.	Feed to mill.	Products from jigs.		Products from tables.		Products from re-treatment of flotation concentrates on tables.	
		Lead concentrates.	Zinc concentrates.	Lead concentrates.	Zinc concentrates.	Lead concentrates.	Zinc concentrates.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Pb.....	6	50	14	68	9	65	12
Zn.....	12	12	35	8	34	10	43
Fe.....	7	7	5	7	10	7	5
Ag.....	±2	±16	±5	±18	±3	±15	±4

± Ounces per ton.

EXAMPLE 4.

Product.	Pb.	Zn.	Ag.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Ounces.</i>
Mill feed.....	5.1	5.8	1.9
Jig concentrates (lead).....	49.5	10.0	12.8
Table concentrates (lead).....	56.6	11.2	9.7
Table concentrates (zinc).....	11.7	23.4	8.6
Flotation feed.....	2.7	5.7	1.8
Flotation concentrates (zinc).....	15.6	25.4	7.8

[In the mill represented by example 4, an attempt is made to eliminate as much lead as possible by jigs and tables from the flotation feed, so that practically all the zinc produced comes from the flotation plant and tables.]

It is apparent from the above examples that there is a considerable loss of zinc in the lead concentrates, and no small amount of lead in the zinc concentrates. The question arises, therefore, as to whether or not a closer separation of the minerals is commercially feasible. Granting that a cleaner product is feasible, what steps should be taken to effect a closer separation, whether (1) by changes and improvements, if possible, in the existing equipment, such as the installation of a finer grinding system which would require more tables, possibly a smaller number of jigs, and a somewhat larger flotation plant, or (2) by a combination of (1) and differential flotation, or (3) by giving the concentrates a flash roast followed by preferential flotation, or (4) by some hydrometallurgical process?

To avoid radical changes in the equipment in the mills and in the methods used, it would seem advisable to carry on research work

along the lines of (1) and (2), namely, to effect a better separation by differential flotation, with whatever changes in the present treatment of the ores this might necessitate, should differential flotation prove successful.

It is along these lines, therefore, that the Bureau of Mines, in co-operation with the University of Idaho and mine operators of the State, will continue to put especial stress on finding some method by which a better commercial separation will be possible. From the number of tests run to date, it is gratifying to state that some very interesting and encouraging results have been obtained.

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LATAH, CLEARWATER, NEZ PERCE, AND LEWIS COUNTIES.

Latah, Clearwater, Nez Perce, and Lewis Counties* contain large areas of basalt flows. In the northern part of Latah County are some areas of granite and Belt sediments, and the eastern part of Clearwater County is underlain with granite and gneiss. The Snake, Salmon, and Clearwater Rivers and their tributaries have cut through the overlying basalt in many places and exposed the older rocks beneath.

LATAH COUNTY.

Latah County contains the following mining districts: Blackfoot (or Gold Hill or Potlatch); Hoodoo or Blackbird; an unorganized district near Troy; an unorganized district north of Moscow in the Thatuna Hills; Robinson or Mica Mountain district; and Ruby Creek district.

BLACKFOOT OR GOLD HILL DISTRICT.

In the Blackfoot district prospecting has been done along the foot of Gold Hill, north of Princeton, and some placer gold has been taken from the creek gravels. The Gold Bug mine, situated at the head of Jerome Creek, has been developed by a shaft and several hundred feet of tunnels, and shows some copper mineral in quartzite, where the latter has been intruded by basic dikes. The occurrence is similar to that at the Mizpah mine, to be described later. No work was being done at the Gold Bug in 1917, and the outlook is not very encouraging. Another place in the district where work has been done is at the Carrico mine, which is also on the south spur of Gold Hill, and shows a somewhat sparse mineralization of specular iron which carries a little gold.

THE HOODOO DISTRICT.

The Hoodoo district is in the northeastern corner of Latah County and adjoins the Tyson Creek district of Benewah County. It is situated 18 miles from Harvard, which is on the Washington, Idaho & Montana Railway, and is reached by a fairly good wagon road.

* Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, 128 pp.

The country rock is mica schist and quartzite, evidently a part of the Belt series. The beds have a remarkably uniform strike and dip and have been intruded by hornblende-diorite sills. Copper minerals are found in zones which are conformable to the strike and dip of the beds and the mineralization is evidently associated with the diorite sills.

The principal property is the Mizpah mine, owned by the Merger Mining Co. Over 2,000 feet of development work, chiefly tunnels, has been done upon this property, but until recently only low-grade disseminated material had been developed. During 1917 copper carbonate ore of good grade was struck, and below the carbonate ore, sulphide ore has been opened up. Several carloads of ore reported to run 13 to 17 per cent copper have been shipped during the summer and fall of 1917. The sulphide ore is chalcopyrite and pyrrhotite, with a little mica, in a gangue of mica schist. Development has not progressed sufficiently to prove the value of this new strike, but the general indications are encouraging.

Undoubtedly a large tonnage of low-grade material will be developed in this mine, as a considerable width of disseminated quartzite that will run one-half to more than 1 per cent copper has been opened in one of the tunnels.

The most important need of this district is railroad transportation, which will probably come when sufficient ore has been developed to warrant construction. Subsequently, problems as to cheap methods of treating the lower grades of ore will doubtless arise.

The mineralization is extensive in this district, but prospecting is difficult on account of the heavy soil covering and forest growth. There is no reason why systematic development should not open up a new copper district of considerable importance to the State.

Adjoining the Mizpah mine is the Copper King mine, where work has been done on a mineralized dike showing copper over a width of 20 feet.

On the North Fork of the Palouse River some gold-bearing quartz veins have been developed to a small extent. Some placer gold, which is now practically worked out, had its origin in these lodes.

TROY DISTRICT.

Copper occurs about 3 miles east of Troy, in the canyons of Bear Creek and its tributaries.

No workable ore has been developed to date, but prospects with very fair showings have been developed on the O. K. Olsen, Gemmill, Halseth, and Copper Chief properties.

The copper minerals are bornite and chalcopyrite in a gangue of gneiss of schist and garnet-bearing limestone.

In the neighborhood of Troy there are some excellent deposits of high-grade fire clay which is residual from granite. Two brick plants are operating, one at Troy, which obtains its clay from a quarry about 8 miles to the east, and the other at Moscow, which obtains the clay from near Joel on the Lewiston branch of the Northern Pacific Railway.

MOSCOW MOUNTAIN AND THATUNA HILLS.

About 6 miles north of Moscow some gold-bearing quartz veins occur in granite. The most extensive workings are upon the White Cross property, which at one time possessed a stamp mill. Very little work was being done at the time the place was visited.

ROBINSON OR MICA MOUNTAIN DISTRICT.

The Robinson district is about 4 miles north of Avon on the Washington, Idaho & Montana Railway. In this district are several pegmatite veins containing muscovite mica in workable amounts,* and this is apparently the only material mined there.

RUBY CREEK DISTRICT.

This district lies on the Elk River branch of the Chicago, Milwaukee & St. Paul Railway. Zinc ore is reported to have been found there, but no ore has been shipped up to the present time. Part of the district is in Clearwater County.

CLEARWATER COUNTY.

Clearwater County is rugged and mountainous. It contains the following districts: Pierce, Moose City, Musselshell, Burnt Creek, and Ruby Creek.

With the exception of Ruby Creek, these are mostly placer camps. Some gold-bearing quartz veins have been found. Copper occurring as bornite is being developed on Oro Grande Creek, some 10 miles northeast of Pierce City, but the extent of the mineralization is unknown. Low-grade lignite coal is found in Clearwater County near Orofino.

NEZ PERCE AND LEWIS COUNTIES.

These two counties are underlain almost entirely by basalt and possess no organized mining districts. Copper ore in greenstone rocks is reported on Deer Creek, which flows into the Salmon River. A company has been prospecting in this district and is reported to have done a considerable amount of development work. The prop-

* Sterrett, D. B., Mica in Idaho, New Mexico, and Colorado: U. S. Geol. Survey Bull. 530, 1911, pp. 375-388.

erty is best reached by a trail from Forest, a small town on Craig Mountain.

In Nez Perce County limestone* of good grade outcrops on the Snake River opposite the mouth of the Grande Ronde River, about 25 miles above Lewiston. This limestone has been used to some extent in the making of cement.

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IDAHO AND VALLEY COUNTIES.

Idaho and Valley Counties, formed from the original Idaho County in 1917, comprise one of the most rugged and inaccessible regions in Idaho, with elevations varying from about 1,000 feet on the Salmon River to over 10,000 feet in the central mountains. (See Plate I.)

The underlying rock is chiefly granite,^a with some inclusions of gneiss and altered sedimentary rock. Some basalt occurs in the western part of the region, and in the eastern part the older rocks are intruded by volcanic rocks.

IDAHO COUNTY.

Idaho County contains the following mining districts: Camp Howard, Cottonwood Buttes, Crook's Corral, Divide Creek, Dewey (Harpster), Dixie, Elk City, Florence, Marshall Lake, Newsome Creek, Oro Grande, Rapid River, Robins (Buffalo Hump), Simpson, and Warren's.

CAMP HOWARD DISTRICT.

The Camp Howard district is contiguous to Whitebird, near Salmon River. Whitebird is 20 miles south of Grangeville and about 2,000 feet lower. Nothing very definite is known of this district.

COTTONWOOD BUTTES DISTRICT.

The Cottonwood Buttes district^b is situated about 5 miles northwest of the town of Cottonwood on the Camas Prairie branch of the Northern Pacific Railway. Here an area of older rocks projecting through the basalt of the plains is reported to contain several veins of quartz, bearing gold, silver, and copper. Little is known of their value.

CROOK'S CORRAL DISTRICT.

The Crook's Corral district is situated on the Snake River slope west of Lucile. The most important property in the district is the

^a Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, pp. 123.

^b Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, pp. 106-107.

Blue Jacket mine, which contains disseminated copper minerals* in a diorite dike reported to be 50 feet wide in places. Over 3,000 feet of development work has been done on the property.

DIVIDE CREEK DISTRICT.

The Divide Creek district is an unorganized district on the Snake River about 50 miles above Lewiston, just above the junction of the Salmon and Snake Rivers, and opposite the mouth of the Imnaha River on the Oregon side. It is reached by motor boat from Lewiston, or else by trail from the Joseph plains, by way of Whitebird.

The country rock is greenstone, which has been intruded by granite, diorite, and other rocks. The mineralized veins are fissure veins ranging up to 10 feet or more in width, and occur both in the greenstone and granitic rocks. The vein material consists of a mixture of almost solid magnetite with some specular hematite. In places some of these veins carry two or three per cent of copper, as chalcopyrite, and also a little pyrite.

There are no producing mines in the district. On the Oregon side the old Eureka mine^b was developed quite extensively and formerly possessed a mill, but is now idle.

DEWEY (HARPSTER) DISTRICT.

The Dewey district is situated on the South Fork of the Clearwater, about 6 miles east of Grangeville and 14 miles above Stites.

The country rock is a complex, highly metamorphosed formation, that might be called a greenstone^c of somewhat obscure origin. The greenstone has been cut by rhyolite and basic dikes. Granite also occurs to the south and west.

The old Dewey property has had more work done upon it than any other in the district. Upon this property there are four roughly parallel veins in the greenstone, two of which have been developed. the St. Patrick and the Dewey. The St. Patrick vein is over 30 feet wide in places and ore occurs along it in the form of shoots or chimneys.

The ore minerals are chalcopyrite, pyrite, arsenopyrite, and a little bornite in a siliceous gangue. Tellurides are reported to occur, but none were identified. Ore running as high as \$500 and \$600 per ton is reported to have been shipped from the property. In the summer

* Bell, R. N., State mine inspector's report, 1911, p. 76.

^b Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, p. 107.

^c Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, pp. 105-106.

of 1917 ore was being shipped by pack horse and wagon to Grangeville that was claimed would run about \$120 to the ton, the values being chiefly gold and a little copper.

A small concentrator with a capacity of 25 to 50 tons a day has been recently installed and the addition of a flotation unit is contemplated. The latter is very necessary, as fine particles of sulphides are visible in considerable quantities in the creek below the concentrator, showing a heavy loss from the present mill equipment.

Another property in the district, which adjoins the Dewey, is the Evergreen. The deposit is of a totally different type from that at the Dewey. Some work has been done on a rhyolite or trachyte dike having a course that roughly parallels the veins on the Dewey. This dike has a width of about 300 feet and has been opened by drifts and crosscut tunnels.

The dike is kaolinized, rotten rock, so that its original mineral composition is obscured. It is filled with small iron-stained seams and is reported to run \$3 to \$4 to the ton in gold. Copper minerals are found in one or two places in the dike, and also in what appears to be a rotten granite along the west side of the dike. If this dike carries the gold values that are reported, it would have considerable prospective value, as there is undoubtedly an enormous tonnage of this material. The great quantity of kaolin present would appear to present a treatment problem which would need a satisfactory solution. Work has been done on only one level at a comparatively shallow depth, and more extensive development would seem justified.

Other properties in the district are the Atlantic, the Marion group, the Oliver Bishop and Solen property, and the Joe Becker property. The ore deposits are supposed to be similar in general characteristics to that at the Dewey mine.

This district seems to be extensively mineralized with a rather uncommon type of ore, which may present metallurgical difficulties in treatment, but better transportation is the principal need. The ore and the concentrates have to be hauled out of a canyon 2,000 feet deep in order to reach the railroad on the plateau at Grangeville. A road up the river from Stites would be of material help to the district.

DIXIE DISTRICT.

The Dixie district* is situated almost in the center of Idaho County, and lies about 80 miles southeast of the town of Stites on the Clearwater branch of the Northern Pacific Railway, from which point it is reached by a wagon road. It is near the head of Crooked Creek.

* Livingston, D. C., and Stewart, C. A., Geology and ore deposits of the Dixie mining district, Idaho: Bull. Univ. Idaho, vol. 9, no. 2, 1914, pp. 11.

which flows into Salmon River. The elevation of the camp is about 5,500 feet.

The country rock is chiefly granite, containing some gneiss inclusions and being cut by many dikes of varying mineral composition. The veins are principally small quartz-filled fissures carrying gold and often a considerable amount of pyrite. These gave rise to placer gravel in the creeks, and the quartz ore itself was usually of good value and free milling near the surface. At a comparatively shallow depth the ore becomes base and can not be amalgamated; also the veins tend to become smaller and more irregular. Very little cyaniding has been done in the district and possibly some of the more persistent veins might become profitable producers if a well-designed mill were installed.

The greatest drawback to the development of the region is its remoteness and the consequent expense of transportation. The fact that it takes a three-day stage journey to cover a distance of 86 miles gives a good idea of the condition of the roads during the greater part of the year.

ELK CITY DISTRICT.

The Elk City district* is situated on the same main wagon road as the Dixie district, but is about 30 miles nearer to the railroad.

The geologic conditions are similar to those of the Dixie district, except that gneiss is more widespread than granite as the country rock. The veins are also very similar in general characteristics, being quartz-filled fissures containing pyrite and smaller amounts of galena, chalcopyrite, and occasionally sphalerite. The gold is free at the surface, but rapidly becomes base with depth.

There are several properties working, and some are producing a certain amount of gold. One of these, the Mineral Zone, appears to be well named, as the ore deposit consists of small high-grade quartz stringers extending over a width of 30 or 40 feet, the whole comprising a low-grade but apparently profitable ore. There seems no reason why this district should not have some mines producing in quantity if the proper attention is given to the milling problems.

A contiguous district of similar characteristics is the Ten Mile, which is situated on the south side of the South Fork of the Clearwater River. In the same vicinity but a little farther east are the South Fork and Center Star mines, which are also of the same general type.

* Flagg, A. L., Elk City mining district: *Trans. Am. Inst. Min. Eng.*, vol. 45, 1913, pp. 113-122; Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho. U. S. Geol. Survey Prof. Paper 27, 1904, pp. 97.

The South Fork mine was a producer for several years. At the Center Star gold-bearing quartz is associated with a diabase dike intruded into granite and gneiss.

FLORENCE DISTRICT.

The Florence district^a is situated on the high divide between the canyon of the Salmon River and the head of Slate Creek, about 40 miles south of Grangeville, and is reached by a wagon road from Grangeville by way of Mount Idaho. This district was one of the richest of the old placer camps. The gold was derived from a series of quartz veins in granite, much like those of the Dixie district but containing less pyrite. Some of the veins have been worked in the past, but there has not been much activity in late years.

MARSHALL LAKE DISTRICT.

The Marshall Lake district lies about 40 miles north of McCall, on Payette Lake, the nearest railroad point, and is reached from there by wagon road. The country rock is principally granite, the formation being similar to that found in other camps of central Idaho. The ore deposits are small quartz-bearing fissure veins carrying gold which is largely free milling. Some concentrates are produced from mills in the district.

This appears to be one of the most promising gold camps of central Idaho, although the ore is somewhat pockety, and the veins are too small for large-scale operations.

NEWSOME CREEK DISTRICT.

The Newsome Creek district is situated on the Elk City-Dixie wagon road, about 50 miles from Stites. This district comprises an old placer camp^b where some gold-bearing quartz veins of the same general character as those previously described have been found, but are not being worked.

ORO GRANDE DISTRICT.

The Oro Grande district is situated on Crooked Creek, one of the tributaries of the South Fork of Clearwater River, and is about 12 miles south of Elk City.

The country rock is mainly granite. Wide zones of gold-bearing rock, supposed to carry \$3 to \$5 per ton, are reported to occur in the

^a Lindgren, Waldemar, The gold and silver veins of Silver City, DeLamar, and other districts in Idaho: U. S. Geol. Survey Twentieth Annual Report, Part III, 1900, pp. 75-256.

^b Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, p. 97.

district. A mill having a daily capacity of 100 tons, and equipped with a cyanide plant, operated for a time on ore from one of these deposits. The venture apparently proved unprofitable, as the mill has been idle for some years.* The failure of this enterprise may have been due to poor sampling, as several other large bodies of ore in the granite belt of central Idaho that were supposed to run \$3 to \$5 have been found to run about a dollar to the ton. In fact, there have been several examples of most disgraceful salting in the past, which has naturally given central Idaho a bad name in many quarters and made the financing of legitimate mining ventures extremely difficult.

RAPID RIVER DISTRICT.

The Rapid River district lies in the western part of the county on Rapid River, one of the tributaries of Little Salmon River. It is reached from Pollock on the Little Salmon by wagon road and trails. Very little prospecting has been done in the district, which may be considered as a northern extension of the Seven Devils district, as the geology is somewhat similar.

ROBBINS (BUFFALO HUMP) DISTRICT.

The Robbins district, situated in the granite belt of central Idaho, lies on the high divide between the drainage areas of Salmon and Clearwater Rivers. The district is reached either from Elk City by way of Oro Grande, or from Grangeville by a branch from the Florence road, the former, although longer, being the easier route. This district had a boom in the late nineties and at one time had several producing mines. Over 20,000 feet of development work has been done in mines of the district.

The ore veins^b are in granite and have the same general characteristics as those of the other districts in the granite area, except that they are somewhat larger. The average width of the veins^c is about 8 feet and they contain free gold associated with mixed sulphides in a quartz gangue. The values are said to run from \$8 to \$15 per ton. The Jumbo mine has been developed to a depth of 800 feet, and very little change in the tenor of the ore has been noted. In fact, recent glaciation of the country precludes to a large extent any extensive secondary surface enrichment.

There are several mills in the district, all of the same type, using simple amalgamation only. The tailings run about \$2.50 per ton,

* From recent information this mill has been run at intervals during 1917.

^b Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 1904, p. 99.

^c Flagg, A. L., Buffalo Hump mining district: Min. and Eng. World, vol. 38, Apr. 26, 1918, pp. 818-814.

which shows the necessity for cyanidation. Concentrates can not be profitably shipped, owing to the cost of freightage.

The drawbacks to the development of this district are (1) the expense of mining due to the high altitude, the heavy snowfall in winter, and the necessity of mining by shaft; (2) the scarcity of timber and consequent excessive power cost; and (3) the expense of transportation, due to the fact that the camp lies on a glaciated and swampy flat about 8,000 feet above sea level. Until these difficulties are overcome, the district is likely to remain dormant. However, the ore is apparently of good grade, and under more favorable conditions there should be several producing mines in the district.

SALMON RIVER (SIMPSON) DISTRICT.

The Salmon River district lies along the Salmon River between Freedom and Riggins. This is chiefly a placer district, and includes the bars and benches along the river.

WARREN DISTRICT.

The Warren district^a is reached from McCall, on Payette Lake, the nearest railroad point, a distance of about 50 miles. The structure is entirely similar in main characteristics, such as formation, veins, etc., to that at Florence, Dixie, and other gold camps of central Idaho. Some of the veins were very rich, although most of them are small, and with cheaper transportation, some of these veins might be worked at a profit.

VALLEY COUNTY.

Valley County contains the following mining districts: Big Creek, Ramy Ridge, Profile, Thunder Mountain, Warm Lake, and Yellow Pine. There are undoubtedly many other mining claims located in different parts of this county, which in the mountainous parts is one of the most inaccessible in Idaho.

BIG CREEK DISTRICT.

The Big Creek district^b lies near the headwaters of Big Creek, one of the largest tributaries of the Middle Fork of Salmon River, between the middle and south forks of that river.

There is a wagon road into the district, but it is practically impassable at times. The nearest railroad point is McCall, on Payette

^a Hill, W. H., The Little Giant mine, Warren, Idaho: Eng. and Min. Jour., vol. 62, Oct. 31, 1896, p. 417; Lindgren, W., The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: U. S. Geol. Survey, Twentieth Annual Report, pt. 3, 1900, pp. 75-256.

^b Bell, R. N., Big Creek gold district, Idaho: Eng. and Min. Jour., vol. 94, Nov. 9, 1912, pp. 891-892.

Lake, about 90 miles distant. A stage runs from McCall to Warren, and the district can be reached by saddle horse from Warren. There are several other routes into the district, but this one is the most direct.

Porphyry dikes have been intruded into granite and metamorphosed sedimentary rocks. The ore is found in quartz ledges which are adjacent to the porphyry dikes. These veins or ledges are 200 to 300 feet in width and contain small amounts of galena and sphalerite with some tetrahedrite. They are reported to run from \$3.50 to \$5 per ton. Several of these large contact veins have been found and probably millions of tons of this class of ore are available. The principal development has been on the Gold King and Independence groups.

The ore can not be amalgamated, but must be either concentrated or cyanided.

With proper transportation facilities, and a well-designed plan of treatment, this district would undoubtedly be a large producer of low-grade ore, and a valuable addition to the mining industry of the State. At the present time it costs more to get freight into the district than into Dawson City on the Yukon. Several high summits have to be crossed, the one near the head of Big Creek being 9,000 feet, and free from snow for only a few weeks in the year.

PROFILE DISTRICT.

The Profile district adjoins the Big Creek district and is in the same belt of eruptive rocks. Very little is known of the ore deposits of the district, but some small shipments of silver and lead ores have been made.

Cinnabar ore also occurs in the district, and was mined on a small scale for its mercury in 1917.

RAMY RIDGE DISTRICT.

The Ramy Ridge district lies about 20 miles east of the Big Creek district on a high ridge between Beaver and Ramy Creeks, tributaries of Big Creek, and is accessible only by trail.

A series of quartz veins, containing free gold at the surface, occur in a somewhat complex geologic formation.

There are several groups of claims owned by prospectors, such as the Hand, the Mahon, and the Thomas properties. At the Thomas property, the only one visited, the ore deposit is a gold-bearing quartz vein 4 to 10 feet wide and exposed for over 400 feet at the surface. This ore will average \$15 to \$20 per ton.

THUNDER MOUNTAIN DISTRICT.

The Thunder Mountain district^a is situated on Monument Creek, a tributary of Big Creek, and is reached by wagon road from Cascade, on the Long Valley branch of the Oregon Short Line Railroad, a distance of about 100 miles.

The ore is gold ore, and occurs as irregular bodies in an unusual type of deposit, consisting of volcanic tuff or hardened mud. These masses surround a cone-shaped butte of the same kind of material. The mass is supposed to run \$2 to \$3 per ton. The best grade of ore found occurred in a vertical fracture in the tuff.

The Dewey mine produced some ore in 1906 and had a 10-stamp mill treating ore which ran \$5.25 per ton. A saving of 85 per cent by amalgamation was effected. On the opposite side of the mountain the Sunnyside mine was worked at the same time, and had a cyanide plant with a daily capacity of 100 tons. The ore was reported to run \$5 to \$10 per ton. These mines have been closed for years, as the ore was too low grade to be profitably worked in such a remote region.

WARM LAKE DISTRICT.

The Warm Lake district is situated near the South Fork of the Salmon River and is reached from Cascade. Practically no information is available in regard to the district, but gold ore of good grade is reported to occur.

YELLOW PINE DISTRICT.

The Yellow Pine district lies on the Thunder Mountain Road, about 60 miles northeast of Cascade.

Little is known of this district, but antimony ore is reported to occur.

DEPOSITS AT DEADWOOD RIVER.

In addition to the above districts, high-grade lead ore is reported to occur on Deadwood River, one of the tributaries of the South Fork of Payette River. The reports indicate a large surface showing.

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^a Bell, R. N., Facts about Thunder Mountain: Eng. and Min. Jour., vol. 74, Aug. 30, 1902, pp. 273-275; Geology of Thunder Mountain and Central Idaho: Eng. and Min. Jour., vol. 73, June 7, 1902, pp. 791-793; Thunder Mountain and Mackay, Idaho: Min. and Sci. Press, vol. 84, Feb. 1, 1902, p. 62; L'Hame, W. E., Thunder Mountain district: Mines and Minerals, vol. 24, December, 1903, pp. 207-209.

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ADAMS AND WASHINGTON COUNTIES.

Adams and Washington counties lie along the Oregon boundary, on the western edge of the State. The topography is varied with a considerable range in elevations. The greatest relief is where the Seven Devils Mountains rise abruptly from the Snake River, with elevations varying from about 1,800 feet at the river to over 9,000 feet on the mountain summits.

The geologic structure is complex and is not very well known; rocks representing almost all the geologic eras occur.

ADAMS COUNTY.

BLACK LAKE (MOUNTAIN VIEW) DISTRICT.

The Black Lake district lies on the east slope of the Seven Devils range on the drainage area of Rapid River. The district is about 50 miles north of Council on the Pacific & Idaho Northern Railroad, and can also be reached by trail from Pollock on the Little Salmon River, or from Homestead on the Snake River.

There is practically no published information in regard to this district, except in the State mine inspector's reports. Local reports on former operations are not promising, and the outlook does not appear to be very bright.

SEVEN DEVILS DISTRICT.

The Seven Devils district* embraces the south end of the Seven Devils range and is about 45 miles north of Council. There is a fairly good wagon road into the district, with a tri-weekly auto stage from Council during the summer months. The nearest railroad point is Homestead, the terminus of a branch line of the Oregon Short Line Railroad from Huntington, Oreg. The distance from Homestead by wagon road is only about 15 miles, but the rise in elevation is nearly 4,000 feet.

Copper ore, consisting chiefly of bornite, occurs as contact metamorphic deposits in crystalline limestone, which has been intruded by diorite.

The area of mineralization is of considerable extent and over 20,000 tons of ore, running 10 to 20 per cent copper, have been

* Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept., U. S. Geol. Survey, pt. 3, 1900, pp. 249-53.

shipped, principally from the Peacock mine. There are a number of claims following a belt of altered limestone for a distance of about 7 miles, all of which show more or less ore of the same kind; that is, bornite and oxidized copper minerals, in a gangue of garnet, epidote, and specular iron.

A different type of deposit occurs in the north end of the district on Deep Creek, a deep and rugged canyon, about 2 miles from the Snake River. This is known as the Red Ledge.* The ore deposit is in red and yellow stained porphyry, and is about 80 feet wide. It contains values in gold and copper reported as \$4 or \$5 to the ton in gold and 1 to 4 per cent copper. Diamond drilling was being done in 1917, and has shown this body of ore to be continuous in depth though somewhat low in grade.

This district will undoubtedly become an important producer of copper when transportation is less expensive than at present, as the distance from the railroads, and the heavy grades to be overcome on the Snake River side are a great handicap.

WASHINGTON COUNTY.

HEATH DISTRICT.

The Heath district is situated 24 miles northwest of Cambridge on the Pacific & Idaho Northern Railway.

Copper deposits^b similar to those of the Seven Devils district are reported as well as lead-silver deposits. Little definite information about the district is available, and the extent and value of the deposits is not known.

HORNET CREEK (GALENA) DISTRICT.

The Hornet Creek, or Galena, district lies at the top of the Cuddy Mountains near the head of Hornet Creek, and is 22 miles northwest of Council. A rough road leaves the main road to the Seven Devils about 14 miles from Council, and most of the distance has to be traveled on horseback.

Lead-silver ore occurs on one property in irregular bunches in limestone.

On the Freese property a flat-dipping quartz vein in diorite or monzonite rock has been exposed for several hundred feet by open cuts and a small shaft. The exact width of the vein was hard to determine, but will probably average 3 or 4 feet. Seemingly several

* Bell, R. N., Verbal report of State mine inspector.

^b Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 75-256; Bell, R. N., State mine inspector's report, 1907, pp. 207-210.

hundred tons of material that will run \$10 to the ton and can be mined by open cut, are available.

MINERAL DISTRICT.^a

The Mineral district is situated about 4 miles east of the Snake River and about 29 miles from Huntington, Oreg. The railroad follows the Oregon side of the Snake River from Huntington to Homestead, and the district is reached by ferry and by wagon road from the Mineral ferry.

The geologic structure is somewhat complex. The country rock is slate and limestone, which has been intruded by porphyry, diorite, and basalt. The ore deposits consist of veins and replacements. The values are principally in silver, with copper in subordinate amounts, the silver being associated with pyrite, chalcopyrite, tetrahedrite, and a little sphalerite in a calcareous gangue.

Formerly the ore was smelted on the ground, and at one time there were two small furnaces in the district. The district became idle when silver dropped in price and has remained so up to the present time. Recently some parties from Idaho Falls have been working a small vein, and have taken out about a carload of shipping ore from near the surface.

At Iron Mountain, 5 miles east of the Snake River, large bodies of magnetite and hematite are reported to occur as contact metamorphic deposits in limestone. Very little is known of the extent or quality of the ore.

MEADOWS DISTRICT.

The Meadows district^b lies about 4 miles east of Meadows, on Goose Creek.

Placer deposits, containing much corundum and other uncommon minerals, occur at the Rock Flat placers. A small amount of gold has been produced.

MONROE CREEK (WEISER) DISTRICT.

The Monroe Creek district is situated 10 miles north of Weiser. The Modoc mine contains gold occurring in a network of quartz seams in a volcanic breccia.

Fuller's earth also occurs in the district.

^a Lindgren, Waldemar, The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 754-756; Turner, H. W., The ore deposits of Mineral, Idaho: Econ. Geol., vol. 3, 1908, pp. 492-502.

^b Bell, E. N., State Mine Inspector's Report, 1912, p. 50.

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ADA, BOISE, ELMORE, GEM, AND OWYHEE COUNTIES.

Ada, Boise, Elmore, Gem, and Owyhee counties are geologically alike and contain similar deposits. With the exception of Owyhee County, they lie on the north side of the Snake River, the deposits occurring in the mountainous area to the north of the Snake River plains. The country rock is chiefly granite with some later intrusives. The area embraced in the mountains is rugged and is reached only by wagon roads. The deposits in Owyhee County are in an isolated range of mountains, with a granite core, somewhat similar to the desert ranges of the Great Basin.

ADA COUNTY.

BLACK HORNET DISTRICT (SHAW'S MOUNTAIN).

This district ^a is situated about 8 miles east of Boise. Quartz veins containing sulphides and some free gold occur in granite. Large tonnages of low-grade ore are reported from some of the mines of the district.

BOISE (McINTYRE) DISTRICT.

The Boise or McIntyre district ^b lies about 3 miles east of Boise. Gold occurs in narrow quartz veins, or in granite along fault seams. Only surface ore has been mined.

Sulphide ore containing sphalerite, galena, and pyrite, with associated gold, which is not free, is reported to occur on the Tornado and Blizzard group.

SNAKE RIVER PLACER DISTRICT.

The Snake River district is situated on the Snake River, where very fine placer gold occurs.

BOISE COUNTY.

BANNER DISTRICT.

The Banner district is situated about 60 miles northeast of Boise and about 25 miles from Idaho City. There is a fairly good wagon

^a Lindgren, Waldemar, Boise Folio, No. 45, U. S. Geol. Atlas, U. S. Geol. Survey, 1908.

^b Lindgren, Waldemar, folio cited.

road into the district. The nearest railroad point is Steirman (35 miles), on a logging road that runs up Moore Creek.

The most important property in the district is the old Banner mine, which produced more than 1,000,000 ounces of silver in the early days. On this property there are four or five roughly parallel quartz veins, containing silver sulphides and sulp-antimonides, with some cerargyrite and native silver. In the summer of 1917 work was being done on the Banner and the Golden Gate veins. The latter vein showed an average stoping width of 30 inches over a length of 300 feet, and is claimed to run about 30 to 40 ounces of silver to the ton. High-grade silver ore was being sorted and shipped by wagon to Steirman. The largest vein, known as the Crown Point, was not accessible at the time of the visit, but a crosscut was being driven to intersect it from the tunnel level.

The old mill had stamps and pan amalgamators. The present owners have remodeled the mill and have installed a flotation system following table concentration.

A similar type of deposit is found about 2 miles from the main wagon road at Moore Summit, or about 15 miles from Idaho City. The property, which is known as the Edna mine, was not visited.

In addition to the silver veins, gold-bearing quartz veins have been found in the district. The Hayfork mine, which is about 10½ miles from Idaho City, shows a deposit typical of the gold-bearing quartz veins of the Idaho granite area.

CENTERVILLE DISTRICT.

Centerville is situated about 9 miles northwest of Idaho City and 44 miles from Boise, and is reached by stage from Boise.

Gold-bearing veins occur in granite, but the district is important principally as a placer camp.

ELKHORN DISTRICT.

The Elkhorn district might be included in either the Centerville or the Gambrinus districts, as the boundaries are indistinct and practically nonexistent. It contains several gold-bearing quartz veins in granite, as at the Fitzhugh, Moriarity, and Clark properties.

GAMBRINUS DISTRICT.

The Gambrinus district is situated 6 miles north of Idaho City and is reached by a fairly good wagon road.

The principal property operating in the district is the Lucky Boy, which has about 3,000 feet of development.

The formation is granite. The ore occurs in a shear zone in the granite, containing a little quartz, and is said to run about \$8 per ton

over a width varying from 5 to 48 feet. The gold is free. The vein material is very rotten and full of clay and rusty iron seams. There is a 10-stamp and Marathon mill on the property, the gold being saved by simple amalgamation. The mill and hoist are operated by electric power generated by a Diesel crude-oil engine.

Two miles beyond the Lucky Boy is the Washington mine, with about 1,500 feet of development and a 10-stamp mill. This mine reported to have opened two parallel veins of the same general character as the Banner mine.

Other properties in the district are the Illinois, Gambrinus, Cleveland, Gentle Annie, and East Eureka.

GOLD HILL, GRANITE, OR QUARTZBURG DISTRICT.

The Gold Hill district^a lies about 51 miles northeast of Boise, and is reached by a good wagon road.

The ore deposits are gold-bearing fissure veins in granite, some of which can be traced for more than a mile. Many of the veins are shear zones in the granite, containing quartz seams, accompanied by much gouge and shattered wall rock. Pyrite is very abundant and stibnite and sphalerite also occur; chalcopyrite and tetrahedrite are in subordinate amounts. The veins vary in width from a few inches to upward of 30 feet. The average value of the ore treated is about \$8 per ton.

The most extensively developed mine in the district is the Gold Hill, but there are many other properties now idle that undoubtedly have large tonnages of low-grade ore.

The future of the district would seem to depend largely upon the proper treatment of the low-grade, base ores, as the free milling ores are nearly worked out. The mills have not, as a rule, been remodeled to fit the changing character of the ore, and the treatment in general consists of amalgamation followed by concentration. In 1917 only concentrates were being cyanided and about 50 per cent of the gold being saved by amalgamation. Other important properties in the district are the Belshazzar and Mountain Chief.

GRIMES PASS DISTRICT.

The Grimes Pass district^b is situated about 6 miles west of Placerville, and is reached by wagon road.

^a Jones, E. L., jr., Lode mining in the Quartzburg and Grimes Pass porphyry belt, Boise Basin, Idaho: U. S. Geol. Survey Bull. 640, 1916, pp. 83-111; Lindgren, W., Mining districts of the Idaho basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 635-736.

^b Jones, E. L., jr., Lode mining in the Quartzburg and Grimes Pass porphyry belt, Boise Basin, Idaho: U. S. Geol. Survey Bull. 640, 1916, pp. 83-111.

The ores occur in fissures, or shear zones, in granite, and consist of quartz and shattered wall rock containing auriferous pyrite, with galena and sphalerite in varying amounts. The deposits are more pyritic than those around Quartzburg.

The principal mines of the district are the Diana, Golden Age, and Mohawk.

At the Diana mine the vein varies from 6 inches to 20 feet in width, averaging about 3 feet. The ore is rather complex, containing coarse galena, sphalerite, and much pyrite. All these minerals carry gold and the galena carries silver. The average value of the ore is about \$20 per ton. The mill at this mine is still in the experimental stage, and makes a concentrate containing all the sulphides, except zinc sulphide, which goes into the tailing and carries gold with it. The concentrates are shipped to smelters at Salt Lake City, Utah.

The Mohawk ore contains copper as chalcopyrite and tetrahedrite, in addition to the other sulphides. There seems to be a considerable amount of ore of good grade at this mine, but the milling problem is unsolved.

The ore at the Golden Age mine is somewhat similar to that at the Diana mine. About 50 per cent of the gold is amalgamated, and two grades of concentrates are made. The concentrates are being stored pending the erection of a cyanide plant.

HIGHLAND VALLEY DISTRICT.

The Highland Valley district lies 18 miles east of Boise. Gold-bearing veins in granite are reported, but little is known of the occurrences in this district.

IDAHO CITY DISTRICT.

The Idaho City district is important chiefly for placer mining. Both dredging and hydraulicking have been extensively carried on in the Boise Basin and the district has been one of the largest gold producers in the State.

Some quartz veins occur, but they are comparatively unimportant.

MOORE'S CREEK AND PIONEERVILLE DISTRICT.

Moore's Creek district is a placer district entirely. Pioneer ville district lies about 12 miles due north of Idaho City. Very little is known of recent developments in the district, but base ore occurs containing pyrite and galena, carrying some gold.

PLACERVILLE DISTRICT.

This is situated around Placerville, and is a placer district chiefly.

SHAW'S MOUNTAIN DISTRICT.

The Shaw's Mountain district lies on the stage road between Boise and Idaho City and is described under Ada County (p. 53).

TWIN SPRINGS DISTRICT.

The Twin Springs district is about 40 miles east of Boise, on the Boise River, where the stream bed shows placer gravels.

ELMORE COUNTY.**ATLANTA (MIDDLE BOISE) DISTRICT.**

The Atlanta district* is situated on the Middle Fork of Boise River, 89 miles northeast of Mountain Home, the nearest railroad point. There is a good wagon road into the district, but the camp is isolated for four to six months in the year through blocking of the roads by heavy snows. The cost of freighting is accordingly high, averaging about 2 to 2½ cents per pound.

The country rock is granite, in which gold and silver bearing fissure veins and shear zones occur. Some of the zones are from 30 to 150 feet in width.

This district was famous in the late sixties and early seventies as a producer of high-grade gold and silver ores. The free milling ores have practically all been worked out, and as the mines gain in depth, the ores seem to be more complex. The chief values are silver in the form of pyrrargyrite and various silver compounds of arsenic and antimony associated with iron sulphides. The two principal mines in the district are the Atlanta Mines Co., controlling the Atlanta, the Buffalo, and the Monarch group of claims, and the Boise-Rochester Mining Co., controlling the General Pettit and the Bagdad-Chase properties. In 1907 and 1908 both these companies erected what were then considered modern mills, the practice being crushing and amalgamation, followed by classification and table concentration, the natural slimes being accumulated and thickened in tanks and treated by cyanidation. The results of milling by this method were not as favorable as they should have been, consequently the Atlanta Mines properties were shut down and not operated for a number of years.

The Boise-Rochester company modified its milling methods from time to time and has operated intermittently since 1908. This company in 1916 installed the Callow flotation process and fairly good results were obtained, the principal difficulty being in handling the flotation concentrates.

Daniel Kirby, manager of the Atlanta Mines Co., has for several years operated the mill that was constructed in 1907 and 1908 on

* Eldridge, G. H., A geological reconnaissance across Idaho: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 211-276.

material from the Monarch mine dump. This dump contained good values in silver and gold which were rejected during the early-day operations. The method of treatment is as follows: The material is crushed to approximately 20-mesh in Huntington mills, the discharge being passed over amalgamation plates to recover the free mineral, followed by classification of the material and careful concentration. The concentrates obtained are roasted in a specially designed furnace and then passed over amalgamation plates to recover any free coarse gold. The roasted ore is then cyanided, and the gold and silver obtained is shipped as bullion, thus eliminating the hauling of any concentrates to the railroads for subsequent shipment to the smelters.

This is a district well worthy of special attention, and if a simple and effective method of treatment by concentration and flotation, or other means, can be worked out, there are enormous deposits of low-grade and complex ores that could be profitably treated.

BEAR CREEK (ROCKY BAR) DISTRICT.

The Bear Creek district lies about 65 miles north of Mountain Home on the road to Atlanta.

The ore deposits are very similar in type to those at Atlanta, but only two or three properties are being worked and these only in a small way.

BLACK WARRIOR DISTRICT.

The Black Warrior district is situated about 100 miles from either Boise or Mountain Home in the mountains north of the plains on the drainage of the North Fork of Boise River and can be reached from Atlanta.

Gold ore occurs in veins in granite. The deposits are somewhat similar to those of the Atlanta district, but the veins are narrower and the ore is of somewhat higher grade. There are several properties in the district, but mining is not very active.

DIXIE DISTRICT.

The Dixie district lies about 25 miles north of Mountain Home, on the South Fork of Boise River. Very little is known of the ore occurrence in this district.

GLENN FERRY DISTRICT.

The Glenn Ferry district is a placer district on the Snake River in the southern part of the county.

HARDSCRABBLE DISTRICT.

The Hardscrabble district lies due south of the Atlanta district on the divide between the middle and south forks of the Boise River. Descriptions of this district may have been included in previous reports, in either the Atlanta or Rocky Bar districts. The writers have been unable to find any information regarding the ore occurrences.

NEAL DISTRICT.

The Neal district* lies 25 miles southeast of Boise on the South Fork of Boise River.

Quartz veins and shear zones in granite, carrying free gold at the surface and auriferous pyrite as depth is gained, are the typical deposits.

PINE GROVE DISTRICT.

The Pine Grove district lies about 45 miles northeast of Mountain Home on the Atlanta road, and can be reached also from Boise.

One of the principal properties is the Franklin, which has a 10-stamp mill and cyanide plant, and is described in the State mine inspector's report for 1909.

OWYHEE COUNTY.**CARSON (WAR EAGLE, SILVER CITY, FLORIDA MOUNTAIN) DISTRICT.**

The Carson district lies on the south side of the Snake River, and is about 23 miles by wagon road southwest of Murphy, the terminus of the branch road from Nampa.

The district is in a range of mountains isolated from the main mountain mass of Idaho and surrounded by lake beds and lava. Granite forms the core of the mountains, and this rock has been intruded by rhyolite and basalt. The veins^b are fissures containing gold and silver-bearing quartz, and occur in the granite, rhyolite and basalt. They do not usually exceed 5 feet in width. The veins occur in three distinct localities: De Lamar, Florida Mountain, and War Eagle Mountain. At one time the Carson district was the most important district in the State, and has produced upward of \$30,000,000 in gold and silver.

One of the reasons for the falling off in production of the district has been the change in the character of the ores from free-milling gold and oxidized-silver minerals to primary sulphides, which has

* Lindgren, Waldemar, Mining districts of the Idaho basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 609.

^b Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 107-187.

been accompanied by a reduction in values. At the present time work in the district is confined principally to the opening of some of the old producing mines at lower levels.

The Trade Dollar Mining Co. at Dewey is extending a lower tunnel, now 3 miles long, under Florida Mountain, and preparing to open up stopes several hundred feet below the old workings. The Sinker tunnel is being driven into the east side of War Eagle Mountain and will be nearly 1,000 feet below the old workings in that locality. The Silver City Mining & Milling Co. and the operators of the Banner mine are also driving deep crosscut tunnels to cut former paying veins at depth.

The future depends entirely upon the discoveries in these tunnels, which, if successful, will give a new lease of life to the district.

The ore, if found at these greater depths, will undoubtedly present milling problems. Treatment of some old dumps is the only milling work going on in the district at the present time.

DE LAMAR DISTRICT.

The De Lamar district lies about 8 miles southwest of Silver City.

The De Lamar was the most important mine in the district and produced more than \$19,000,000 in gold and silver. The country rock is principally rhyolite and the deposits are fissure veins carrying native gold and silver sulphides in a quartz gangue. The De Lamar mine shut down in 1914 and has been idle ever since, but there are believed to be valuable ore bodies still left in the mine.

The ores are similar to those of the Carson or Silver City district and would probably be amenable to the same methods of treatment. Cyanidation was employed in recent years, and this superseded the old pan-amalgamation process formerly used.

CASTLE CREEK DISTRICT.*

This district lies about 25 miles southeast of Silver City. Robert N. Bell, the State mine inspector, reports a number of excellent prospects in the district, showing lead, silver, and copper. At one property a small experimental stamp mill and cyanide plant was operating in 1915.

The amount of development in the district has been small.

FLINT DISTRICT.

The Flint district^b lies about 9 miles southwest of Silver City, about the head of a small gulch emptying into Jordan Creek.

* Bell, R. N., State mine inspector's report, 1906, p. 130, and 1912, p. 148.

^b Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 187-199.

Veins carrying tetrahedrite, pyrite, and silver sulphides and sulphur-antimonides occur in granite and diorite. The veins vary in width from a few inches to several feet. The most extensive work has been done upon the Perseverance property.

MAMMOTH DISTRICT.*

The Mammoth district is situated 33 miles south of Murphy, and 7 miles southeast of Silver City.

Several veins ranging up to 20 feet in width occur in granite. The vein filling is milky quartz, carrying pyrite, but there does not seem to be any information available as to the values or contents of these veins.

SOUTH MOUNTAIN DISTRICT.

The South Mountain district lies about 18 miles southwest of Silver City.

The ore occurs as veins and contact metamorphic deposits in a belt of schists and crystallized limestone. The ore is argentiferous galena with sphalerite and copper minerals, in a quartz-calcite gangue.^b The ore is said to run 20 to 60 per cent lead, and 40 to 100 ounces of silver to the ton. The ore body on the Golconda property was eight feet thick.

The district is somewhat difficult of access and not much is known of the deposits there.

GEM COUNTY.

PEARL (WILLOW CREEK, GEM, ROCK CREEK) DISTRICT.

The Pearl district^c is situated 8 miles northeast of Emmett. The ore occurs as gold-bearing quartz veins and impregnation zones along porphyry dikes in granite. The veins are usually narrow, seldom exceeding 4 feet in width. Ore running \$30 to the ton has been shipped from the district, but a considerable amount of the ore seems to be of low grade.

SQUAW CREEK OR BODIE DISTRICT.

The Squaw Creek district is situated on Squaw Creek about 15 miles northeast of Emmett. According to records of the General Land Office in Boise, mineral claims have been patented in this district; no information is available as to the extent or character of the deposits.

* Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 188.

^b Bell, E. N., State mine inspector's report, 1906, p. 130, and 1912, p. 146.

^c Lindgren, Waldemar, Mining districts of the Idaho basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 707.

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BLAINE, BUTTE, CAMAS, CUSTER, LEMHI, AND FREMONT COUNTIES.

Blaine, Butte, Camas, Custer, Lemhi, and Fremont counties are best considered under one head, as the topographic and geologic conditions, as well as the ore deposits, are somewhat similar.

The area embraced in these counties is the rugged mountainous region that lies north of the Snake River plains, where the ranges rise abruptly from the plains to elevations of upwards of 12,000 feet. Long structural depressions, like valleys, between the mountains in the southeastern part connect with the plains. (See Plate I.)

The geologic structure is complex; the formations being metamorphosed sedimentary rocks, overlain by limestone, shale, and quartzite with intrusions of granite and volcanic eruptive rocks. Faulting and folding are very pronounced.

BLAINE COUNTY.

ANTELOPE DISTRICT.

The Antelope district lies on Antelope Creek, 17 miles southwest of Darlington, on the Mackay branch of the Oregon Short Line Railroad, and is reached by wagon road.

The only mine in the district^a is the Antelope mine, where about 2,000 feet of development work has been done on veins of lead-silver ore in limestone. Upwards of 30 cars of ore running about 16 per cent lead and 16 ounces of silver to the ton have been shipped from the mine.

ELKHORN (KETCHUM) DISTRICT.

The Elkhorn district lies on Elkhorn Creek about 3 or 4 miles southeast of Ketchum, the terminus of the Hailey branch of the Oregon Short Line Railroad.

Fissure veins in limestone, containing argentiferous galena in a siderite and calcite gangue, are the principal deposits of the district.

The old Elkhorn mine was the chief producer at one time, but the ore was lost at a fault. Other mines of the district are the Quaker

^a Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, 1917, p. 119.

City, Parker, and North Star. The deposit at the Quaker City mine contained tetrahedrite.

In late years there has not been much activity in the district.

GALENA DISTRICT.

The Galena district is situated 26 miles northwest of Ketchum. This district at one time possessed a 30-ton lead smelter, but is now comparatively unimportant and is practically deserted.

LAVA CREEK DISTRICT.

The Lava Creek district is situated 20 miles west of Arco, on the Mackay branch of the Old Salt Lake Railroad, and is reached by stage from that point.

The country rock is chiefly of volcanic origin. At the Hub mine^a sulphide ore, carrying 4 per cent lead and 100 ounces of silver to the ton, occurs somewhat irregularly in a fault zone 30 feet wide.

At the head of Lava Creek tungsten occurs as the mineral hübnerite in a vein of crushed quartz about 5 feet wide.

MULDOON DISTRICT.

The Muldoon district lies 24 miles east of Hailey and is reached by a wagon road from that point.

The country rock is principally quartzite, cut by igneous dikes. A lead-silver deposit^b of considerable value and extent has been worked out at the Muldoon mine. The mode of occurrence and the characteristics of the ore body are not very well known, but very high-grade lead ore was formerly mined there. There is a concentrator on the property, which is now practically idle.

Also, a copper deposit of low grade has been found in the district.

The 26-mile haul from the railroad is a considerable handicap to mining in this district, as the roads are in bad condition for a considerable part of the year.

ROSETTA DISTRICT.

The Rosetta district^c is situated in the vicinity of Carriatown, about 22 miles east of Ketchum, and is reached from that point by a wagon road, which is not particularly good.

The rock formations include limestone and other sedimentary rocks, bordered by lavas and the granite batholith of Idaho. The

^a Umpleby, J. B., *Geology and ore deposits of the Mackay region, Idaho*: U. S. Geol. Survey Prof. Paper 97, 1917, p. 122.

^b Umpleby, J. B., work cited, p. 106.

^c Umpleby, J. B., *Ore deposits in the Sawtooth quadrangle, Blaine and Custer Counties Idaho*: U. S. Geol. Survey Bull. 580, 1915, p. 233.

ore deposits are replacements and veins, containing argentiferous galena, tetrahedrite, and sphalerite, in a quartz-siderite gangue, with considerable wall rock. The ores are mined principally for their silver content, which averaged 100 to 200 ounces to the ton.

The most productive mine of the district has been the Carrie Leonard. However, the rich silver-bearing galena ore of the upper part of the vein gave place to sphalerite with depth, and the mine is now idle. Other mines of the district are the Dollarhide, Isabella, Margaret, Silver Star, Silver Crown, King of the West, Sunday, Stormy Galore, and Tyrannus.

The district seems to have passed out of the producing stage, largely due to change of character in the ore and impoverishment of the ore shoots with depth.

SAWTOOTH DISTRICT.

The Sawtooth district^a is situated southwest of Alturas Lake, and can be reached from Ketchum.

In this district silver-bearing quartz veins occur in granite. The district has been idle for many years, and most of the workings are inaccessible. High-grade silver ore is reported to occur in the lower workings of some of the mines.

VIENNA DISTRICT.

The Vienna district^b is at the head of Smiley Creek, one of the branches of the Salmon, in the high mountainous area forming the divide between the Boise, Wood, and Salmon Rivers. The district can be reached from Ketchum. It is in the granite area of central Idaho.

Something like 20,000 feet of development has been done in the district. The only accessible workings are those of the Mountain King mine, which shows that the ore body was about 700 feet long with widths up to 15 feet. The ore contained galena, and other sulphides in quartz, and carried gold and silver to the value of more than \$20 per ton. Some ore, shipped in 1912, ran over \$50 to the ton. The district is now practically deserted.

WARM SPRINGS DISTRICT.

The Warm Springs district^c lies in the northern part of the county, about 16 miles west of Ketchum, and is reached by a wagon road.

^a Umpleby, J. B., work cited, p. 240.

^b Umpleby, J. B., work cited, p. 247.

^c Umpleby, J. B., work cited, p. 240.

The ore occurs near a contact of granite and slate. The ores were lead ores running high in silver. The district has not been actively productive since about 1887.

WOOD RIVER (HAILEY) DISTRICT.

The Wood River district* covers a considerable area contiguous to the towns of Hailey and Bellevue, and is one of the most important in the State.

The principal ore deposits are fissure veins carrying argentiferous galena with a siderite gangue in sedimentary rocks. Some of the many mines having this type of deposit are the Minnie Moore, Red Elephant, North Star, Triumph, Queen, and Mascot. A smaller number of veins of the same type occur in granite. The Democrat mine is an example of this type.

Another type of deposit found in this district is gold-bearing quartz veins in granite and diorite, containing small amounts of chalcopyrite and pyrrhotite.

In the early days, the lead ores mined frequently ran 100 ounces of silver to the ton, but the ores exposed in the lower workings are lower grade, more complex, and contain more sphalerite.

The North Star and Triumph mines were purchased by the Federal Mining & Smelting Co. in 1916. The ores at these mines are complex ores of lead, silver, and zinc, a typical assay being 0.04 ounce of gold per ton, 12 ounces of silver per ton, 12 per cent lead, 19 per cent zinc, 16 per cent iron, and 24 per cent insoluble.

The Federal company during 1916 and 1917 made exhaustive tests on these ores to devise a means of successfully separating the lead and zinc into commercial shipping products. The results have, to a certain extent, been successful, but the problem has not been fully solved, the difficulty being to get a clean-cut separation between the lead and zinc. The experimental treatment of these ores has included differential flotation by the use of sulphuric acid, different oils, and, in some instances, alkaline reagents. In other experiments and tests the ore was first roasted to oxidize the iron and afterwards treated with electromagnetic machines, the aim being to remove the iron from the zinc, leaving the nonmagnetic material of sufficiently high grade to ship to the zinc smelters. Although this has served as a treatment method, still the nonmagnetic concentrate has not all been sufficiently high in zinc to make a desirable product for the zinc smelters. The content of lead, iron, and insoluble material has been too high, and such concentrate can only be treated at a residue zinc smelter. The company is still making exhaustive tests under the direction of T. M.

*Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other districts in Idaho: Twentieth Ann. Rept. Geol. Survey, pt. 3, 1900, pp. 190-209.

Owen, general mill superintendent of the company, of Wallace, Idaho. The best prospects for a successful ore-dressing treatment seems to be differential flotation, using suitable addition agents. Latest reports from this district are to the effect that the company has also taken over the Independence group of claims near Hailey.

The Mascot Mining & Milling Co.,* operating the Mascot group, was shipping ore in 1917, and also installing additional equipment and doing considerable development work. A good road connects this property with the railroad. Charles Peter, of Salt Lake City, is president of the company.

BUTTE COUNTY.

DOMES DISTRICT.

The Dome district^b lies partly in Butte County and partly in Fremont County, at the southern end of the Lemhi range. It is reached by stage from Arco, on the Mackay branch of the Oregon Short Line Railroad, a distance of about 50 miles.

The country rock is chiefly quartzite, with some beds of shale and magnesian limestone.

There are several prospects in the district, but the only mine which has been actively worked in recent years is the Wilbert mine. On the Wilbert group about 4,000 feet of development work has been done. The ore deposits occur along a fracture zone caused by a steep anticlinal fold, and are very irregular in form. The width of the ore bodies varies from a few inches to 7 or 8 feet. The ore is disseminated galena in quartzite and galena as the cementing material in a quartzite breccia. The lead contents of the different ore shoots vary considerably. There is a concentrator on the property with a daily capacity of 100 pounds.

The Wilbert Mining Co. has been a constant shipper to the Utah smelters during the past year, the high-grade ore averaging about 8 ounces of silver to the ton, and 50 per cent lead. The concentrate shipped to the smelters assays about 8 ounces in silver and 55 per cent lead. A. S. Ross is manager of the company.

Other properties in the district are the Johnson, Great Western, and South Creek, their distribution showing the district to be widely mineralized.

CAMAS COUNTY.

CAMAS DISTRICT.

The Camas district is situated north of the Camas Creek branch of the Old Salt Lake Railroad in T. 1 N., R. 17 E.

* News Item, Salt Lake Mining Review, vol. 19, Feb. 28, 1918, p. 41.

^b Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, 1917, pp. 113-118.

The country rock is granite and diorite, and the deposits are gold-bearing fissure veins. The gangue is quartz and siderite, with sulphides in small amounts. The gold is principally free milling. The veins are wide, some being upwards of 40 feet, and contain pay streaks varying from 5 to 8 feet in width.

Stamp mills were operated in the district in the early days.

LITTLE SMOKY DISTRICT.

The Little Smoky district^a lies south of the Rosetta district in Blaine County, and by some writers is included in that district. The Little Smoky district is somewhat inaccessible. Deposits of lead-silver ore of good grade are reported. At the Hidden Treasure mine there is reported to be ore blocked out that will average 15 to 20 per cent lead, 10 ounces of silver per ton and 0.2 ounce of gold. There are many other lode claims, but little is known of the extent and character of the ores.

SKELETON CREEK DISTRICT.

Claims have been staked near the head of Skeleton Creek, one of the tributaries of the South Fork of the Boise, but seemingly no information is available concerning the character and occurrence of the mineral deposits.

SOLDIER DISTRICT.

The Soldier district, situated on Soldier Creek, is reached from Fairfield on the Camas Creek branch of the Oregon Short Line Railroad.

There is practically no information on the district, but placer gold seems to have been the principal output.

Tungsten is reported to occur on Soldier Mountain at the head of Soldier Creek.

CUSTER COUNTY.

ALDER CREEK (MACKAY) DISTRICT.

The Alder Creek district^b is situated in southeastern Custer County, at the terminus of the Mackay branch of the Oregon Short Line Railroad. Mackay is the principal town. This is the most important copper-producing district in the State.

A railroad owned by the Empire Copper Co. extends from Mackay 7½ miles to the mines. The ore at the Empire mine occurs chiefly in

^a Umpleby, J. B., Ore deposits in the Sawtooth quadrangle, Blaine and Custer counties, Idaho: U. S. Geol. Survey Bull. 580, 1915, p. 240.

^b Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, 1917, pp. 93-106.

the granite and consists of irregular bodies or shoots of chalcopyrite in a gangue of garnet, with smaller amounts of pyrite and pyrrhotite. Some of these bodies are very extensive.

The principal producer of the Mackay district is the Empire company, of which L. R. Eccles, of Ogden, Utah, is president, and F. A. Behling, manager at the mine. The company contemplated the erection of a mill in May, 1917, but this did not materialize as the property changed management about that time. However, an aerial tramway is being built from the mine to the old smelter where the ore is loaded, this distance being 4 miles. The smelter at Mackay has not been operated for about 10 years. All the ore is shipped to the American Smelting & Refining Co., at Garfield, Utah, direct from the mine. The ores are only roughly sorted. The average assays of the shipments run from 2.5 to 3 per cent copper, 1.5 to 2 ounces of silver per ton, and 0.02 ounce of gold. The property is divided into blocks and the leasing system is generally followed.

The latest reports are to the effect that a mill of approximately 1,000 tons daily capacity is contemplated, the object being to treat the ores that are too low grade to ship direct to the smelters. The mining will be done by steam shovels and much of the low-grade ore now on the mine dumps can probably be profitably treated in the milling plant.

On properties adjoining the Empire company's ground on the west, silver-lead ores have been mined, the Keenan having been the largest shipper. During the high price of lead in 1917 these properties were active but in the fall of the year, when the price of lead declined, almost all of them suspended shipments. The ore is rather low grade, averaging about 5 per cent lead with some silver.

The Horseshoe company in this district is also working its property and sorting ores for shipment. The sorted ores average about 20 per cent lead and carry enough iron to make the ores desirable to the smelter.

BAY HORSE DISTRICT.

The Bay Horse district* lies in the west-central part of Custer County in the vicinity of the big northern bend of the Salmon River. The district is reached either by stage from Salmon City or from Mackay, by way of Challis. Mackay is the principal supply point, and is about 60 miles distant.

According to Umpleby,^b there are two fairly well defined types of ore deposits—lead-silver and silver-copper.

* Umpleby, J. B., Some ore deposits in northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, 1913, pp. 55-76.

^b Umpleby, J. B., work cited, pp. 58-59.

The primary ores of the lead-silver type are argentiferous galena in a gangue of quartz and siderite, with other sulphides in subordinate amounts. The ore bodies are somewhat irregular and are usually inclosed in limestone or dolomite. Most of the ore mined in the past was oxidized material. The Beartsley-Excelsior and Red Bird veins are typical of this class of deposit.

The silver-copper deposits usually occur in slate as ore shoots in either bed or fissure veins. The ore shoots average 100 feet in length and vary from a few inches to 4 feet in width. About three-fourths of the vein material in the shoots is siderite, and one-fourth is argentiferous tetrahedrite containing more than 30 per cent copper and nearly 5 per cent silver; galena, arsenopyrite, pyrite, and sphalerite occur in small amounts. The ore bodies at the Ramshorn, Skylark, and Silver Bell mines are examples of this type of deposit. The average ore from these shoots is reported to run between 3 and 8 per cent copper, and 80 to 125 ounces of silver per ton. Hand-sorted ore has run far in excess of these figures.

Formerly two smelters and a concentrator were at work, but there has been little activity in recent years, most of the mine owners preferring to leave the ore in the mines until transportation facilities are improved. If a railroad were built to this district, it would undoubtedly be an active producer.

EAST FORK DISTRICT.

The East Fork district^a lies on the north of Germania Creek, one of the tributaries of the East Fork of Salmon River. This area is one of the most rugged regions in the State, some of the adjacent peaks having elevations reported to be more than 12,000 feet, and one peak over 13,000 feet. The district is reached by wagon road from Ketcham, a distance of about 50 miles. It is 25 miles by trail from Clayton.

Some lead-silver ores were mined during the early days of the district, but the more important type of deposit is the low-grade gold-bearing quartz vein. The country rock is quartzite and limestone, intruded by granite porphyry. The veins consist chiefly of coarse, bluish quartz, and in addition to gold contain pyrrhotite. They vary in width from a few feet to more than 70 feet. The gold content is reported to run from about \$3 to more than \$12 to the ton, and to be fairly uniform throughout the veins. The veins are persistent and the outcrops can be traced in some places for distances of several thousand feet.

^a Umpleby, J. B., Ore deposits in the Sawtooth quadrangle, Blaine and Custer Counties. Idaho: U. S. Geol. Survey Bull. 580, 1915, p. 244.

HAMILTON OR CLYDE DISTRICT.

The Hamilton district is situated on Little Lost River about 28 miles northeast of Mackay.

Some shipments of lead-carbonate ore were made in 1915; also some copper ore has been shipped. Very little is known of the ore bodies in this district.

LOON CREEK DISTRICT.

The Loon Creek district^a lies in the northwestern part of the county and is reached by wagon road from Mackay, a distance of 110 miles. Two high summits have to be crossed in this distance.

The most important ores are the gold-copper deposits at the Lost Packer and adjacent properties.

The Lost Packer vein is a fissure vein, traceable for a distance of 3,000 feet, and has been explored by tunnels for 2,000 feet of its length. The average width of the vein is about 20 inches, the ore occurring in three distinct shoots. The ore is auriferous chalcopyrite in a gangue of siderite and quartz and carries a little silver. Most of the ore mined in the past has run \$70 to \$90 to the ton, but there is reported to be about 2½ tons of ore that will run \$25 developed in the mine to every ton of the higher-grade ore.

The ore is smelted at the mine, as there are plenty of suitable fluxing materials in the vicinity. Coke costs about \$46 per ton laid down at Ivers.

Veins of similar character to that at the Lost Packer have been found in the immediate vicinity, but very little development work has been done upon them. Placer mining is also an important industry, the gold being derived from gravel benches by hydraulicking. Silver-lead deposits also occur in the district, but have not been worked.

YANKEE FORK DISTRICT.

The Yankee Fork district^b is situated in the northwestern part of the county, 85 miles from Mackay and is reached by wagon road from that point. The surrounding country is high and rugged.

The district has been a large producer of gold in the past, but is practically idle at the present time. The ore deposits are gold and silver bearing quartz veins in volcanic rocks. The proportion of gold and silver vary greatly at the different mines. The veins occur in two parallel systems 4 or 5 miles apart, each system containing

^a Umpleby, J. B., Some ore deposits in northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, 1913, pp. 90-100.

^b Umpleby, J. B., Some ore deposits in northwestern Custer County, Idaho: U. S. Geol. Survey Bull. 539, 1913, pp. 76-90.

four or five veins, varying in width from stringers to 18 feet, averaging about 4 feet. The vein filling is fine-grained chalcedonic quartz containing sulphides among which pyrite predominates; gray copper mineral also is present and probably carries the silver. The gold is free but is extremely fine. The ore also contains selenium.

The most important mine in the district was the General Custer, which operated from the late seventies until 1905, but has been idle since that time. The best ore has undoubtedly been worked out, but whether the veins are barren in the lower workings or of low grade is not stated in any reports on the district. There are several mills but none of them is working.

COPPER BASIN DISTRICT.

The Copper Basin district* is situated near the head of the East Fork of Big Lost River, about 23 miles west of Mackay, at an elevation of 7,000 feet.

Copper ore, very similar in general characteristics to that at the Empire mine near Mackay, and lead-silver ore occur in the district.

The Copper Basin Mining Co. did considerable prospecting and development work during 1917. About 50 carloads of crude ore, averaging 8 to 12 per cent copper, was shipped from this company's property to the smelters at Salt Lake.

The Star Hope mine consists of a quartz vein containing partly oxidized galena and some other sulphides.

BOULDER DISTRICT.

According to the records of the general land office in Boise there is a mining district at the head of Boulder Creek, near the high divide between the Salmon River and the East Fork of Salmon River. No further information was available.

SHEEP MOUNTAIN DISTRICT.

The Sheep Mountain district is situated 130 miles northwest of Ketchum and is accessible only by trail.

Argentiferous galena, associated with antimonial silver minerals, occurs in this district, and also sulphide ores of pyrite and pyrrhotite, carrying good values in gold. The inaccessibility of the district is its principal drawback, as there are many promising prospects.

SEAFOAM AND GREYHOUND DISTRICTS.

The Seafoam and Greyhound districts are practically one and are situated on the drainage area of the Middle Fork of the Salmon

* Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, 1917, p. 103.

River, about 120 miles northwest of Ketchum. The road into the district is fairly good, but crosses several high summits, making the open season very short.

The country rock is chiefly granite, cut by porphyry dikes. The ores are complex sulphides and sulph-antimonides, carrying gold, silver, lead, and copper, and occur in fissure veins, varying in width up to 5 or 6 feet.

At the Greyhound property on Sulphur Creek a concentrator and smelter was in operation at one time, but this mine has been idle for several years.

Nineteen samples taken on the Burns property showed contents ranging from traces up to 0.98 ounce gold per ton, 38.2 ounces silver per ton, and 29.7 per cent lead, the average being 0.15 ounce gold, 8.1 ounces silver, and 3.7 per cent lead.

There seems to be a number of these veins in the district, very few of which have been developed, but indications point to a considerable tonnage of these complex ores.

The difficulties of transportation effectually prevent the shipping of any but the highest-grade material, and the success of the district would seem to depend upon the discovery of a process by which such ore can be concentrated before shipment.

Results of analyses of 19 samples from Burns property.

Sample No.	Gold.		Silver.		Copper (per cent).	Lead		Total value per ton. ^a
	Ounces per ton.	Value per ton.	Ounces per ton.	Value per ton.		Per cent.	Value per ton.	
1	0.02	\$0.41	0.8	\$0.64	-----	Tr.	-----	\$1.05
2	0.01	0.21	Tr.	Tr.	-----	Tr.	-----	0.21
3	0.20	4.13	36.8	29.44	-----	29.7	\$44.55	78.12
4	0.16	3.31	13.6	10.83	-----	10.7	16.06	30.34
5	Tr.	Tr.	0.5	0.40	-----	0.6	-----	0.40
6	0.07	1.45	1.8	1.44	-----	Tr.	-----	2.89
7	0.08	1.65	4.0	3.20	-----	3.3	4.95	9.80
8	Tr.	Tr.	Tr.	Tr.	-----	None.	-----	-----
9	Tr.	Tr.	0.4	0.32	-----	Tr.	-----	0.32
10	0.35	7.25	38.2	30.56	-----	7.7	11.55	49.36
11	0.18	3.72	13.8	11.04	-----	5.7	8.55	23.31
12	Tr.	Tr.	0.4	0.32	-----	Tr.	-----	0.32
13	Tr.	Tr.	Tr.	Tr.	-----	None.	-----	-----
14	Tr.	Tr.	Tr.	Tr.	-----	None.	-----	-----
15	0.24	4.96	6.4	5.12	-----	10.4	15.80	25.68
16	0.98	20.25	1.0	0.80	(b)	None.	-----	21.05
17	0.11	2.27	1.2	0.96	0.13	Tr.	-----	3.23
18	0.23	4.75	0.3	0.24	None.	None.	-----	4.99
19	0.33	6.82	34.7	27.76	-----	3.0	4.50	79.08

^a Figures are for prices in August, 1917.

^b Sample showed a trace of copper; was also analyzed for zinc (none) and arsenic (4.34 per cent).

DESCRIPTION OF SAMPLES.

1. Open pit on north point of ridge between Lakeview and Silver Bell. Unlocated ground. Strong Fe gooson 5 feet wide.
2. Gem claim. Average of vein in face of drift. Vein only 1 foot wide.
3. From pile of high grade on dump lower tunnel, Silver Bell, 10-ton pile. Grab sample, taken in attempt to get average.

4. Grab sample from 20-ton pile of second-class ore on dump at lower tunnel, Silver Bell.
5. Grab sample, main dump lower tunnel, Silver Bell. Represents several hundred tons.
6. Grab sample, upper tunnel, dump, Silver Bell. Represents 75 tons.
7. Sample across 3½-foot face of vein on foot-wall side. Fifty feet in from portal, lower tunnel, Silver Bell. Vein is 5 feet wide, but the 1½ feet next to hanging wall was sampled separately and numbered sample 8.
8. Sample across 1½ feet of vein next to hanging wall, lower Silver Bell tunnel.
9. Sample across 3 to 4 foot vein exposed in face of upper tunnel, Silver Bell. Vein looks lean.
10. Sample of high-grade sacked material from upper dump, Silver Bell, represents 40,000 pounds.
11. Sample represents 140 tons of second-grade ore, upper dump, Silver Bell.
12. Sample taken across face in lower Shephard tunnel. Rock is sheeted, but no ore in sight.
13. Face of upper Shephard tunnel. Some oxidized-lead ore on dump. None visible in tunnel.
14. Upper tunnel dump of Shephard, near place where sample 13 was taken.
15. Sample of surface material, from open pit, center of north-end line; Shephard vein, about 3 feet wide.
16. Represents west face at crosscut in Lakeview tunnel. Across 4-foot vein.
17. Cut from east face in Lakeview tunnel.
18. Sample taken across 4-foot vein back halfway between two faces, Lakeview tunnel.
19. Dump at open cut on Hasbrook's property, just above camp. Grab-sample average of dump.

LEMHI COUNTY.

The descriptions of the districts in Lemhi County are taken chiefly from Umpleby's report,^a as these were not visited in 1917.

BLACKBIRD DISTRICT.

The Blackbird district^b is situated on the drainage area of Big Creek about 35 miles southwest of Salmon City and reached by a wagon road from that point. It is a high region with elevations ranging up to 7,500 and 8,000 feet.

The underlying rocks are principally metamorphic mica-schists and quartzites. Mineralization is widespread, the district containing gold and copper deposits as well as cobalt and nickel.

Umpleby reports 2 per cent of cobalt in a sample taken across a 20-foot ledge, and 2 per cent nickel in another sample taken across the same ledge in another place.

BLUE WING DISTRICT.

The Blue Wing district^c lies on Patterson Creek, a tributary of the Parsimeroi River and is 20 miles southwest of Leadore.

The country rocks in this district, as in the Blackbird, are metamorphic rocks. It is noted for the occurrence of tungsten as hüb-

^a Umpleby, J. B., *Geology and ore deposits of Lemhi County, Idaho*: U. S. Geol. Survey Bull. 528, 1913, 182 p.

^b Umpleby, J. B., work cited, p. 159.

^c Umpleby, J. B., work cited, p. 108.

nerite, which occurs in quartz veins, together with an extraordinary number and variety of other minerals.

There is a mill in the district and tungsten concentrates have been shipped for several years.

CARMEN CREEK DISTRICT.

The Carmen Creek district^a is situated about 15 miles northeast of Salmon City at the head of Carmen Creek.

Quartz veins carrying gold, associated with sulphides, and replacement deposits in schist, carrying copper, occur in this district.

ELDORADO DISTRICT.

The Eldorado district^b lies 9 miles east of Salmon City. The country rock is metamorphic, and the ore deposits are gold-bearing quartz veins carrying sulphides. Placer mining has also been conducted.

EUREKA DISTRICT.

The Eureka district^c lies on the west side of Salmon River. Salmon City is in approximately the center of the southern half of the district. The boundaries between this district and the Mackinaw district are poorly defined.

GIBBONSVILLE DISTRICT.

The Gibbonsville district^d is situated in the northern end of the county on the drainage of the North Fork of Salmon River. The district is reached by wagon road from Salmon City, a distance of about 30 miles. It is in the belt of quartzites and slates.

The ore deposits consist of a series of narrow gold-bearing quartz veins, containing a considerable amount of pyrite in some places. The district has yielded upward of \$2,000,000 in gold from 8 or 10 of these veins. Most of the veins are less than a foot wide.

The gold values are \$10 to \$40 per ton. The gold is intimately associated with the pyrite, and the ore yields only about 40 per cent of the gold by amalgamation.

GRAVEL RANGE DISTRICT.

The Gravel range district^e is situated on the divide between the Salmon River and the Middle Fork of Salmon River, and is about 35

^a Umpleby, J. B., work cited, p. 125.

^b Umpleby, J. B., work cited, p. 123.

^c Umpleby, J. B., work cited, p. 155.

^d Umpleby, J. B., work cited, p. 128.

^e Umpleby, J. B., work cited, p. 172.

miles southwest of Salmon City in a direct line. It is reached by wagon road from Salmon by way of Leesburg and Forney.

The principal country rock of the district is rhyolite, and the ore deposits are of different type from those in the districts previously described.

The Monument mine is the best developed property in the district. At this property, along a brecciated zone about 40 feet wide, occurs a quartz lode 3 to 8 feet wide, which is reported to run about \$11 per ton in gold and silver. Some pyrite is present in the quartz, but it is thought that possibly the gold and silver are present as a selenides.

The type of ore deposit represented by this property presents an interesting metallurgical problem. After considerable experimentation with ore from the Monument mine, a combination of the cyanide and the chlorination system was installed. The results obtained in the mill evidently did not come up to the results of the experiments, as the mill shut down on account of the low recovery, after operating only a short time. The ratio in ounces of silver to gold is about 18 to 1. With the high price of silver now prevailing, it would seem that a cheap method of treatment for these ores is worth investigating.

INDIAN CREEK DISTRICT.

The Indian Creek district^a lies on Indian Creek, on the north side of the canyon of the Salmon River, about 30 miles below Salmon City. A stage runs to Ulysses, the only town in the district.

The two principal veins of the district are the Kittie Burton and the Ulysses. The Ulysses is a flat vein, practically a bedded deposit, about 10 or 12 feet wide, which dips with the slope of the hill, so that in some places the vein is stripped and quarried. The ore is gold-bearing quartz carrying pyrite and some other sulphides, and is milled by a combination of amalgamation and concentration. Amalgamation is reported to recover 80 per cent of the gold.

The Kittie Burton is a somewhat similar vein, although with a steeper dip, and is as much as 30 feet wide in its flatter part.

Other veins occur in the district, but so far as is known none is producing at the present time.

JUNCTION DISTRICT.

The Junction district^b is a somewhat irregular and poorly defined district, contiguous to Junction and Leadore, on the Gilmore & Pittsburgh Railroad.

^a Umpleby, J. B., *Geology and ore deposits of Lemhi County, Idaho*: U. S. Geol. Survey Bull. 528, 1913, pp. 134-136.

^b Umpleby, J. B., work cited, p. 114.

The principal rocks of the district are limestones and quartzites overlain unconformably by lake beds. There are also porphyry intrusions. The ore is fine-grained argentiferous galena, mixed with small amounts of pyrite and occasionally a little chalcopyrite. The ore is usually free from gangue, and occurs along a fault in the contact between the lake beds and older sediments, in rather narrow shoots, the high-grade ore running about 30 ounces of silver to the ton and 55 per cent lead.

The principal property of the district is the Leadville group, but other claims have been located along the fault for a distance of over 5 miles.

KIRTLEY CREEK DISTRICT.

The Kirtley Creek district^a is situated east of Salmon City and comprises a small area lying between the Eldorado and Carmen Creek districts.

The geologic formations and the ore occurrences are similar to those of the Eldorado district. The principal property is the White Horse, at the head of Kirtley canyon.

MACKINAW DISTRICT.

The Mackinaw district^b is situated in the high area on the south side of Salmon River opposite the Indian Creek district. Leesburg is the principal settlement and is reached by stage from Salmon City.

The district has produced a considerable amount of placer gold, which was derived from the quartz veins or lodes which occur in different parts. These lodes are sometimes as wide as 300 feet, and consist in some places of small quartz stringers in granite or schist, the whole forming a low-grade ore.

Deposits of several different types are mentioned by Umpleby, most of them being large and of low grade. Some lead ore has been reported from the district.

McDEVITT DISTRICT.

The McDevitt district^c lies north of the Junction district and extends along both sides of Lemhi Valley, and is traversed by the Gilmore & Pittsburgh Railroad.

Sedimentary and metamorphic rocks outcrop on the east side of the valley and basalts and rhyolites on the west side. The Copper Queen mine, near the continental divide, is the only property which has passed the prospect stage. At this mine several veins of quartz

^a Umpleby, J. B., work cited, p. 124.

^b Umpleby, J. B., work cited, pp. 145-148.

^c Umpleby, J. B., work cited, p. 118.

occur in quartzite rock. The principal vein averages about $3\frac{1}{2}$ feet wide, but varies considerably. The ore contains chiefly copper minerals. Eighteen tons of copper concentrate from a stamp mill equipped with tables averaged 28.3 per cent of copper and 6 ounces of silver. The ore occurs in irregular shoots, the richest of which have been mined, but there is a large tonnage of lower grade material, the economic handling of which would probably involve a treatment problem.

MINERAL HILL DISTRICT.

The Mineral Hill district^a lies west of the Indian Creek district along the Salmon River. Shoup, the trading center of the district, is reached by stage from Salmon City.

In this district gold-bearing quartz veins occur in gneiss, which are evidently similar to the quartz veins of Idaho County and other districts in the granite region of central Idaho.

NICHOLIA DISTRICT.

The Nicholia district^b is situated in the southeast corner of the county, near the continental divide.

The Viola mine was worked for lead up to about 20 years ago and a smelter was erected at Nicholia to treat the ore. The ore was lead carbonate, and occurred in large, irregular but connected bodies in limestone, and ran 35 to 60 per cent lead, 4 to 14 ounces of silver, and contained iron and manganese oxides. The ore in this mine was apparently lost by faulting and seemingly a revival of the mine would depend on finding the vein again.

PARKER MOUNTAIN DISTRICT.

The Parker Mountain district^c is situated southwest of the Gravel Range district on the drainage of the Middle Fork of the Salmon River, near the heads of the stream, and is reached by trail from Custer County. The district is new, and has only a small production.

The ore deposits are of the same type as those of the Gravel Range district, which have been previously described, and occur in the volcanic rocks. The veins vary in width, with a maximum of 8 or 4 feet. The values are in gold and silver, with gold predominating.

PRATT CREEK DISTRICT.

The Pratt Creek district^d lies about 15 miles southeast of Salmon City and adjoins the Eldorado district to the north.

^a Umpleby, J. B., work cited, p. 140.

^b Umpleby, J. B., work cited, p. 84.

^c Umpleby, J. B., *Geology and ore deposits of Lemhi County, Idaho*: U. S. Geol. Survey Bull. 528, 1913, p. 177.

^d Umpleby, J. B., work cited, p. 121.

The most extensively developed mine is the Goldstone, where several thousand feet of work has been done on a quartz vein carrying chalcopyrite and galena, but mined principally for gold. There is a mill on the property which has treated about 1,000 tons of ore.

SPRING MOUNTAIN DISTRICT.

The Spring Mountain district^a is situated about 8 miles south of Gilmore, the southern terminus of the Gilmore & Pittsburgh Railroad, and lies in the Lemhi Range.

The country rock is chiefly limestone, intruded by diorite dikes. The ores are lead and silver ores in replacement veins in limestone. Most of the ore mined up to the present time has been oxidized material, the shipments varying from 15 to 50 per cent lead, and from 3 to 15 ounces of silver to the ton. A 50-ton smelter was built at Hahn in 1909 to treat the ores of the district, but it closed down after two short runs. A large low-grade deposit of copper, associated with magnetite, is reported to occur on Dry Gulch.

TEXAS DISTRICT.^b

The Texas district^b adjoins the Spring Mountain district to the north. The principal town is Gilmore on the Gilmore & Pittsburgh Railroad.

The ore deposits are similar in character to those of the Spring Mountain district, but have been more extensively developed. They occur as replacement veins in limestone.

At the Pittsburg-Idaho mine there are two nearly vertical veins connected by a flatter vein. The ore occurs in shoots in the veins, and consists almost entirely of oxidized metallic mineral, such as earthy lead carbonates, iron, and manganese oxides. The average ore runs about 15 ounces of silver to the ton and 37 per cent lead, and is shipped direct to the smelters.

At the Latest Out mine the ore is similar in character and occurs in much the same way as that at the Pittsburgh-Idaho mines. Besides these lead deposits, there is a vein in the Allie property which is mined for its gold content only. This vein comprises iron and manganese oxide with visible free gold, and a large tonnage of this kind of ore has been blocked out that is estimated to run \$12 to the ton. This ore is also shipped direct to smelters.

The Silver Moon, a property south of Gilmore, has produced about 80,000 ounces of silver. The ore contains very little lead.

The Texas district has produced about \$3,000,000 to date and is the most important district in the county at the present time.

^a Umpleby, J. B., work cited, pp. 84-87.

^b Umpleby, J. B., work cited, p. 89.

YELLOW JACKET DISTRICT.

The Yellow Jacket district^a is situated in the western part of Lemhi County and is reached from Salmon City by a wagon road about 50 miles in length. Another wagon road connects it with Challis in Custer County.

The veins occur in sedimentary rocks, and have been worked for gold since 1868. Some placer mining has been done in the district. At the Yellow Jacket mine a 15-foot vein of gold-bearing quartz, which averages about \$8 per ton, has been developed by tunnels. There is a stamp mill on the property, the gold being saved by amalgamation. Other mines in the district are the Black Eagle, Red Jacket, and Columbia.

FREMONT COUNTY.**SKULL CANYON DISTRICT.**

The Skull Canyon district^b is situated in the northwestern corner of Fremont County and about 40 miles west of Dubois, the nearest railroad point on the Butte branch of the Oregon Short Line Railroad.

The country rock is chiefly magnesian limestone and quartzite. The ore deposits of the district include lead-silver ores and copper ores. The 4-foot vein on the Weaver and Kaufman claims is highly oxidized lead ore. Several thousand feet of work have been done upon this property, and some high-grade ore containing several ounces of silver to the ton has been shipped to Dubois. Also copper ore occurs at the Weaver mine. The ore deposit consists of heavily iron-stained "jaspery" material, containing chrysocolla, malachite, azurite, chalcopryite, and unimportant amounts of other copper minerals. The deposit varies in width from a few inches to 6 or 7 feet on the northeast side of the canyon and up to 25 feet on the southwest side. The mine was actively worked at one time, the ore being hauled to Dubois.

BUCK CREEK DISTRICT.

The Buck Creek district^c lies on Buck Creek about 10 miles southeast of Kaufman and 36 miles from Dubois on the Butte branch of the Oregon Short Line Railroad.

^a Umpleby, J. B., work cited, pp. 165-168.

^b Umpleby, J. B., *Geology and ore deposits of the Mackay region, Idaho*: U. S. Geol. Survey Prof. Paper 97, 1917, p. 110.

^c Gale, H. S., and Richards, R. W., *Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah*: U. S. Geol. Survey Bull. 430, 1909, pp. 457-535; Richards, R. W., and Mansfield, G. R., *Geology of the phosphate deposits northeast of Georgetown, Idaho*: U. S. Geol. Survey Bull. 577, 1914, 76 pp.

The rocks of the district are chiefly limestone and dolomite. The Buck Creek mine, the only one in the district, has a vein averaging about 4 feet wide containing lead minerals carrying 10 to 25 per cent lead.

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THE SOUTHEASTERN COUNTIES.

Bannock, Bear Lake, Bonneville, Cassia, Madison, and Teton Counties comprise a part of the Snake River plains, and also the mountainous area in the southeastern corner of the State. The topography of this area is not as rugged as that of the central mountains of Idaho, but the elevations exceed 9,000 feet in several places.

The most important mineral deposit is high-grade phosphate rock, which underlies large areas in Bannock, Bear Lake, Bingham, Bonneville, Madison, Teton, and Fremont Counties. These deposits have been fully described in recent publications^a of the United States Geological Survey.

Outside of the Snake River plains the underlying rocks are chiefly folded sediments.

BANNOCK COUNTY.

FORT HALL DISTRICT.^b

The Fort Hall district is situated 9 miles east of Pocatello and 1½ miles from Portneuf siding on the Oregon Short Line Railroad.

The principal property of the district is the Fort Hall mine. The ore deposit at this property is a wide fissure zone in shale containing bands of quartz and calcite inclosing chalcopyrite, pyrite, and a little galena. The zone is 125 to 140 feet wide, and the mineralized quartz bands range up to 5 feet in width.

The principal values are in the copper, but small amounts of gold, silver, and lead also are present.

Several thousand feet of development work have been done upon this property, and a mill has been erected. The mill is in ruins, as the property has been idle for years.

There are thousands of tons of low-grade material on the dump, and the property would seem to warrant more attention than its present dilapidated condition indicates. Other properties in the district are the Apollo Group, Recovery, Moonlight, and Papoose.

SODA SPRINGS DISTRICT.

Some mining claims have been patented in an unorganized district near Soda Springs on the Oregon Short Line Railroad. Sulphur

^a See bibliography at end of the chapter.

^b Weeks, F. B., and Helkes, V. C., Notes on the Fort Hall mining districts, Idaho: U. S. Geol. Survey Bull. 340, pp. 175-183, 1908.

occurs in this district, and the deposits have been described by Richards and Bridges.^a The sulphur does not appear to be in commercial quantities.

BEAR LAKE COUNTY.

BEAR LAKE DISTRICT.

The Bear Lake district^b is situated in the vicinity of Montpelier. In this district mineral deposits have been found in two localities—one in the Bear River Range to the west of Montpelier and the other about 4 miles to the east. In the latter locality copper carbonates occur, principally as stains in joint planes and cracks, in a bed of shale. This copper-bearing shale outcrops along a north and south line for a length of about 9 miles, and prospect pits have been sunk along the greater part of this distance.

Selected rock running as high as 2 per cent copper can be obtained from some of the workings, and in places the material might be worked at a profit by using some cheap leaching process. No sulphide ores have as yet been opened up.

In the Bear River Range are lead deposits carrying a little gold and silver. In 1896 several carloads of ore and concentrates which averaged about 80 per cent lead were shipped from the Blackstone mine. From Richards's description^c this deposit is seemingly a flat blanket in limestone, about 8 feet thick. Ore has also been shipped from the Humming Bird mine near Paris. Copper ore as chalcopyrite and tetrahedrite also occurs in the district.

BONNEVILLE COUNTY.

MOUNT PISGAH (CARIBOU MOUNTAIN) DISTRICT.^d

The Mount Pisgah district is situated on Caribou Mountain to the east of John Gray Lake. The nearest railroad point is Soda Springs, about 42 miles in a southwesterly direction. The district at one time was active as a placer camp, gold occurring in the gulches on the northeastern slope of the mountain. This placer gold was derived from mineralized beds of quartzite, in which diorite sills are intercalated and which outcrop near the summit of the mountain. These

^a Richards, R. W., and Bridges, J. H., Sulphur deposits near Soda Springs, Idaho: U. S. Geol. Survey Bull. 470, pp. 499-504, 1910; abstracted in Min. and Eng. World, vol. 36, Jan. 6, 1912, p. 12.

^b Gale, H. S., Geology of the copper deposits near Montpelier, Idaho: U. S. Geol. Survey Bull. 430, 1910, pp. 112-121.

^c Richards, R. W., Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: U. S. Geol. Survey Bull. 470, pp. 177-187.

^d Kirby, Edmund B., The gold ore deposits of Mount Caribou, Idaho: Colorado Sci. Soc. Proc., vol. 5, 1898, pp. 72-75; Lakes, Arthur, Mount Caribou gold deposits: Mines and Minerals, vol. 19, September, 1898, pp. 55-58.

beds of quartzite vary in thickness from 3 to 60 feet, but there is no available information as to the value of their gold contents. High-grade copper ore is also reported to occur in the district.

CASSIA COUNTY.

STOKES (CANNON CREEK) DISTRICT.

The Stokes district lies on Cassia Creek about 38 miles southeast of Burley. The Salt Lake & Idaho Railroad is the nearest point of railroad transportation. Quartz veins containing lead ore associated with gold, silver, and copper are reported.

BLACK PINE DISTRICT.

The Black Pine district is situated in the southeastern corner of the county and may possibly be in Oneida County. This is a new district from which some zinc carbonate ore was shipped in 1916. No further information is available as regards the deposits.

OTHER DISTRICTS.

In addition there is a placer gold district on the Snake River and some low-grade lignite on Goose Creek.^a The latter has been reported upon by the United States Geological Survey. In Power County there is a placer district on the Snake River.

MADISON COUNTY.

CANYON CREEK DISTRICT.

The Canyon Creek district lies on Canyon Creek about 25 miles southeast of St. Anthony and extends into Teton County.

Nothing is known of the ore occurrences in the district, but mineral claims have been patented there.

TETON COUNTY.

On Horseshoe Creek occur workable deposits of coal of good grade, the only known workable coal seam in the State. This district has been reported upon by Woodruff^b and is fully described by him.

^a Russell Israel C., Geology and water resources of the Snake River plains of Idaho: U. S. Geol. Survey Bull. 199, 1902, pp. 192.

^b Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, 1912, pp. 389-398.

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PRELIMINARY REPORT ON THE HORSESHOE DISTRICT OF THE TETON COAL BASIN, SOUTHEASTERN IDAHO.

• BY GEORGE WATKIN EVANS.

INTRODUCTION.

The Teton coal field, in southeastern Idaho, is sometimes referred to as the St. Anthony coal field, as the Teton Basin coal field, and as the Horseshoe Basin coal field. It might be well in this report to refer to it as the Horseshoe Basin coal field and thus avoid confusion for the reason that other areas in the Teton Basin might be developed and later reports on these fields made.

MAPS.

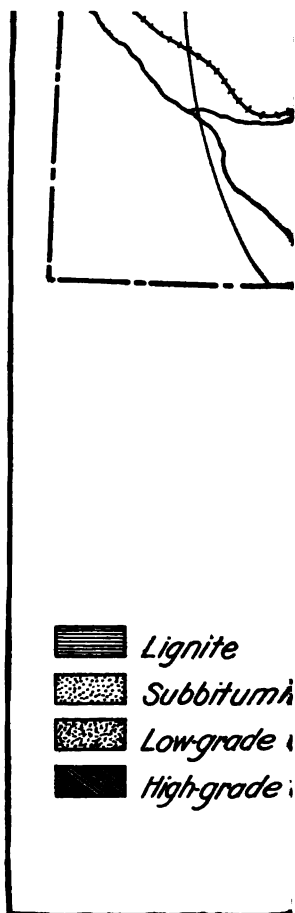
Plate III, an outline map of Idaho and parts of Montana, Wyoming, and Utah, shows the locality of the Teton coal field, which is the subject of this report, and also the localities of other coal fields, some of which furnish coal for the district that the Teton coal field is tributary to. This map was traced from the map that accompanies Professional Paper 100-a of the United States Geological Survey. In addition to showing the location of the several coal fields that might be considered tributary to southeastern Idaho, the relative positions of the several towns that might be benefited by coal from this field have been indicated by circles showing their distance from the town of Driggs, from which station this coal would be shipped.

Figure 1 shows the location of the county road that connects the coal field with the railroad, and by dotted lines the approximate location of the railroad survey that would connect the railroad with the coal mines.

Figure 2 was compiled from personal observations of the writer and from Plate XXII, of Bulletin 541* of the United States Geological Survey. This map shows the extent of the coal area as determined by Woodruff.

Figure 3 is a sketch map of the Brown Bear mine and was made from a compass survey by the writer during his visit in this field. It is plotted to a scale of 200 feet to 1 inch. The dotted lines show the

* Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, 1912, pp. 379-388.



SKETCH MAP OF IDAHO

probable extensions of the underground workings which were not accessible at the time the writer visited this property.

LOCATION.

The Teton coal basin, as will be noticed by referring to Plate III, is situated in the southeastern part of the State of Idaho, not far from the western line of the State of Wyoming.

It is more exactly described as follows: As occupying a part of sections 5 and 6 in T. 4 N., R. 44 E.; section 1 in T. 4 N., R. 43 E.;

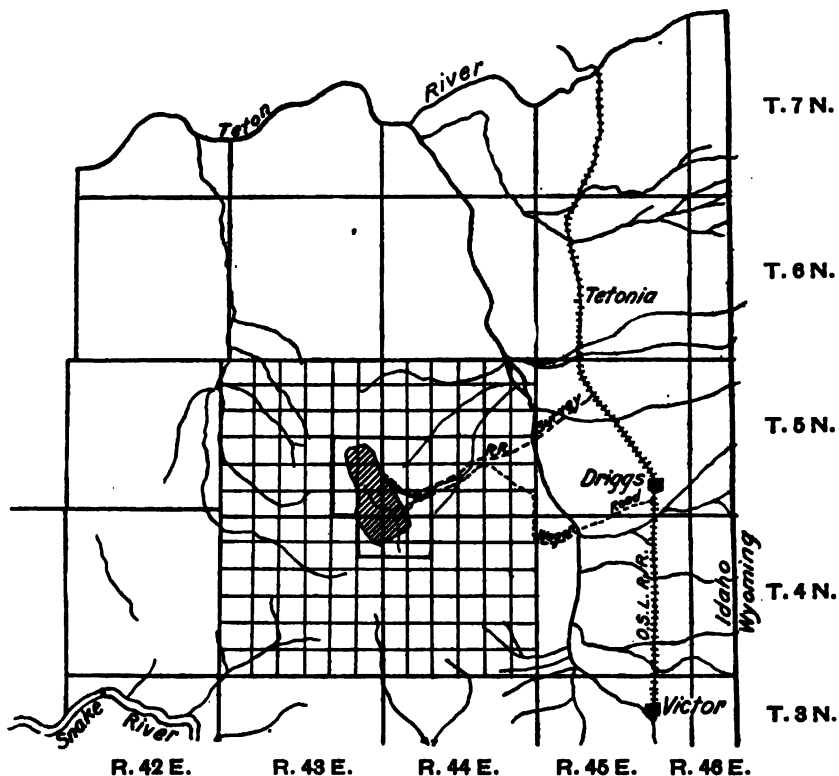


FIG. 1.—Sketch map showing relative positions of Horseshoe district coal field, railroad connections, and shipping points.

sections 30 and 31 in T. 5 N., R. 44 E., and sections 23, 24, 25, 26, and 36 in T. 5 N., R. 43 E. According to Woodruff* this field contains approximately 6 square miles of coal area. The coal mines are located directly west of Driggs, a distance of about 10 or 11 miles in a direct line, and are connected with that place by means of a fairly good wagon road. Driggs is a small farming center with a population of probably 800 or 1,000 people, and is on a branch of the Oregon Short Line Railroad, which runs from Ashton to Victor.

* Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho. U. S. Geol. Survey Bull. 541, 1917, pp. 379-388.

TOPOGRAPHY.

The elevation of Driggs is about 6,000 feet above sea level, the land to the westward is comparatively flat for about 8 miles, when the foothills of the mountains are reached, and the surface is more or less rugged from this point to the Horseshoe and Brown Bear mines. The topography is such that a railroad could very easily be built to a point within 4 miles of the coal mines, and it is claimed that a very satisfactory railroad grade can be had from the mouth of Horseshoe Creek Canyon to the mines with a maximum grade of 3 per cent. By following the eastern limit of Horseshoe Creek, it

seems certain that a satisfactory tram road can be built from the mouth of the canyon to the mine at a moderate cost.

Immediately surrounding the openings at the Horseshoe and Brown Bear mines, the surface is more or less rolling; and, so far as the topography is concerned, there are no insurmountable difficulties, as the property is rather easily accessible. The area, after the foothills are reached, is covered with a fair growth of spruce, hemlock, and fir; and the district, no doubt, contains sufficient timber of good quality for mining purposes to last for 15 or 20 years, allowing for a considerable production of coal.

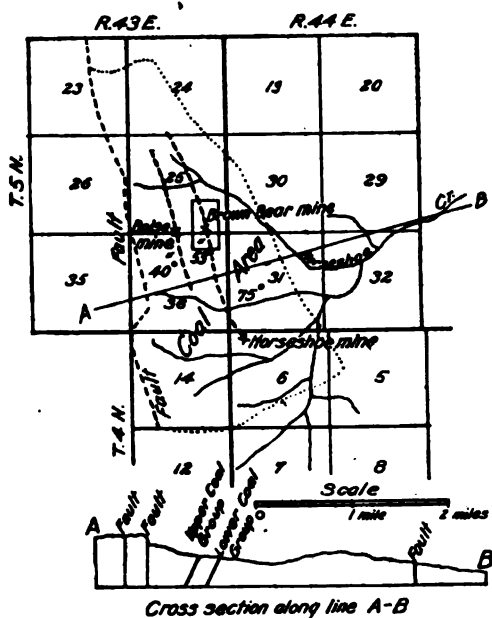


FIG. 2.—Sketch map showing extent of coal-bearing area of the Horseshoe district, Teton County, Idaho. Small square shows area represented in figure 2, after Woodruff.

Horseshoe Creek and the other small streams flowing through this district produce a sufficient amount of suitable water for all domestic and coal-washing purposes. The openings at the Horseshoe and the Brown Bear mines are approximately 900 feet above the elevation of Driggs.

GEOLOGY.

STRUCTURE.

The following is a condensed discussion of the structure by Woodruff:*

The rocks in the main part of the district dip steeply to the southwest, whereas the strata on the east side are only slightly inclined and those on

* Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, 1917, pp. 379-388.

the west are horizontal. In the southern part of the district the structure is complicated, but in general the rocks dip steeply to the north. The structure of the sedimentary rocks in the northern part of the district is concealed beneath recent lava flows. The most probable interpretation of the very diverse structural phenomena is that a great fault lies along the western margin of the field, with the downthrow on the east and the upthrow on the west, and that on the east side of the district there is a similar, perhaps equally profound, fault, along which the movement has been in the same direction. Between these two faults lies a large block of strata that is tilted downward to the west.

FAULTS.

In addition to the above might be added the following:

By referring to figure 3, based on a compass survey made by the writer, one can see the relationship of the faults and the coal bed. These faults are normal, and, although they add to the expense of mining operations in this field, they are not fatal to the commercial value of the field and are no worse than the faulting that occurs in several of the present operating mines in the State of Washington.

GEOLOGICAL AGE.

According to Woodruff^a the coal beds are of Paleozoic age.

COAL BEDS.

Three separate outcrops, which probably represent three separate and distinct beds, were examined.

COAL BED AT HORSESHOE MINE.

At the Horseshoe mine, shown in figure 2, the following cross section of the coal bed was obtained:

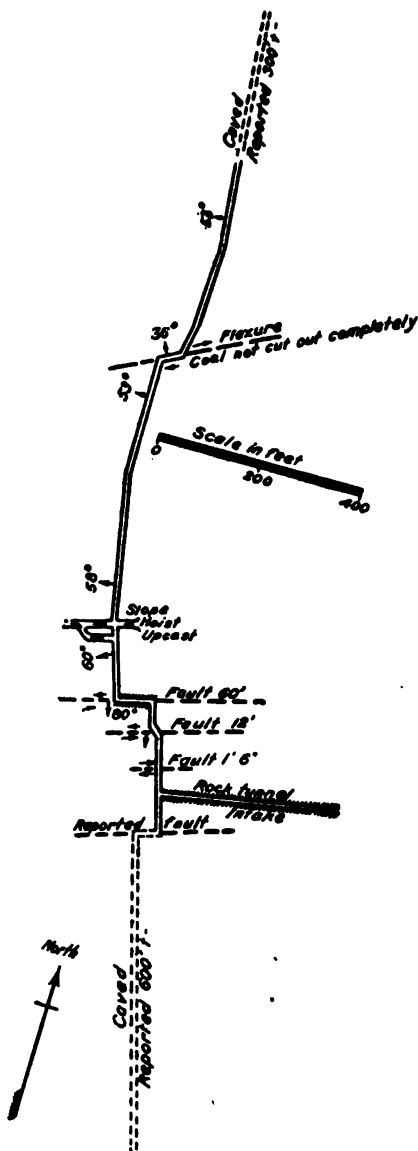


FIG. 3.—Sketch map of Brown Bear coal mine, Horseshoe district.

^a Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, 1917, pp. 379-388.

Section of coal bed at Horseshoe drift.

	Ft.	in.
Roof, shale.		
Coal	2	0
Clay		11
Coal	9	0
Floor, shale.		

The strike of the coal bed is N. 30° W., and the dip is about 66° SW. The gangway at the time the mine was visited had been driven a distance of approximately 115 feet. A detailed section of the coal could not be had, and it is not known whether the lower 9 feet of coal is free from impurities or not. The coal appears to be firmer than the coal in the Bell Gulch drift.

COAL BED AT BELL GULCH DRIFT.

The coal bed at the Bell Gulch drift, no doubt, is the same as the one in the Mormon tunnel at the Horseshoe mine, and is, beyond a doubt, the Horseshoe bed. The following is a cross-section of the bed at the Bell Gulch drift:

Cross section of coal bed at Bell Gulch drift.

	ft.	in.
Roof, dark shale.		
Coal ^a	3	0
Dark shale		1
Light shale, fine-grained		9
Good coal ^a	3	3
Carbonaceous shale, hard		1
Coal, soft ^a		7
Carbonaceous shale	2	0
Floor, dark shale.		

The bed strikes N. 30° W., and dips 78° southwest.

The coal at this particular place, although apparently of good quality, is more or less crushed, and the percentage of lump coal would probably be small.

BROWN BEAR BED.

The bed known as the Brown Bear coal bed is overlain with hard resistant sandstone with flint-like nodules. In places, local lenses of shale occur between the sandstone and the coal. The following is a section of the bed, measured at the slope of the mine.

Section of coal bed at Brown Bear mine.

	ft.	in.
Roof, sandstone.		
Coal, very good, hard ^b	3	1
Soft, dark shale		4
Coal ^b	1	0
Crushed coal, impure		8
Floor, hard shale.		

^a Included in sample 1; for analysis see page 97.

^b Included in sample 2; for analysis see page 97.

The strike of the bed is N. 17° W. at the slope where the foregoing cross section was taken. The dip is approximately 60° west.

At the rock tunnel about 350 feet south of the slope, the following cross section was measured:

Section of coal bed at rock tunnel.

	ft. in.
Roof, sandstone.	
Coal, good, hard -----	3 4
Coal and shale mixed -----	2
Coal -----	1 0
Impure coal, crushed -----	3
Floor, sandy shale.	

BOISE BED.

The coal bed known as the Boise bed was not exposed at the bottom at the place sampled. The sample represents 3 feet 5 inches to 3 feet 9 inches of coal. The analysis is given as sample 3, on page 97. The bed strikes north and south, and dips 40° west. The roof is a massive sandstone, that has major and minor joints, the major joints being parallel with the dip, and the minor joints nearly parallel with the strike. These joints will undoubtedly cause caving in breasts that are driven wider than the width of the jointing system, and the roof will require a considerable amount of timber.

GENERAL.

As previously indicated, the writer believes that the Horseshoe coal bed and the Brown Bear coal bed are two separate and distinct coal seams, but this fact can be proved only by tracing the beds through the intervening area and correlating them absolutely. The Boise bed, which overlies the Brown Bear bed, is clearly a separate one and must be considered as such.

Woodruff^a states that the coal beds occur in two groups about 1,100 feet apart stratigraphically; that the upper group contains only one bed and the lower group comprises three beds in the northern part of the field, one in the central part and two in the southern part.

Robert N. Bell, mine inspector for the State of Idaho, states^b that there are two principal coal beds in this district one of which is 5 feet thick and the other 10 feet thick, and that there are 18 separate and distinct coal beds in this part of the field.

QUALITY OF COAL.

The coal at the Brown Bear mine has a black shining luster, and no doubt with careful mining will yield 30 to 50 per cent lump.

^a Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, 1917, pp. 379-388.

^b Bell, R. N., State mine inspector's report for 1915, p. 115.

Where the beds are less steep than in the present workings a larger percentage of lump could be obtained. The coal exposed in the seam at the Horseshoe mine is much more friable. The bed at that place inclines at a steep angle, and the workings had penetrated only a short distance below the outcrop. The friability of the coal is probably due to earth stresses, aided by weathering.

Two distinct uses could be made of this coal within the district tributary to the coal area—for domestic use and for fuel in railroad locomotives, and also in the various coal-burning power plants in this part of Idaho. Another possible, important use is for powdered fuel for smelters, as the coals have a very large percentage of volatile matter and a small percentage of ash and would no doubt prove satisfactory for such use.

TONNAGE.

A reliable estimate as to the probable tonnage of this field can not be drawn. The continuity of the beds has been determined along the strike, but the depth to which they extend below surface is still an unknown factor. By referring to figure 2 (p. 92), it will be noticed that Woodruff represents a fault as occurring to the westward and that with depth the coal beds are completely cut off.

If Woodruff's assumption is true the coal beds would only reach a limited depth, and it is not known what this depth might be. The beds have been traced along their strike for approximately 2 miles. Assuming that they continue along the dip for half a mile, there would be a square mile of coal area in each bed. The Bell Gulch and the Horseshoe outcrops, no doubt, represent the same bed. These two outcrops average about 9 feet of coal. This bed if it proves to be a separate bed from the Brown Bear bed, and will average 6 feet of minable coal, would be expected to contain 4,992,000 tons, on the basis of 1,300 tons to the foot-acre, which is a close enough basis, considering the accuracy of the data at hand. On the same basis, the Brown Bear bed, if the average thickness be taken as 4 feet, would comprise 3,330,000 tons, and the Boise bed, assuming an average thickness of $3\frac{1}{2}$ feet, would contain 2,912,000 tons. Thus, the total for the three beds would be more than eleven millions of tons. No one is justified in assuming that this amount of coal has been proved in this district, but the foregoing figures are given as a suggestion of the probable tonnage. The actual tonnage can be determined only by actual gangway and slope development.

ANALYSES OF COALS.

HORSESHOE DISTRICT, TETON COAL BASIN, SOUTHEASTERN IDAHO.

The analyses of samples of coal collected in the Horseshoe district by G. W. Evans, in October, 1917, are given in the following.

The analyses were made by H. A. Depew, assistant physical chemist, Seattle station of the Federal Bureau of Mines.

Results of analyses of coals from Horseshoe district.

BELL GULCH BED.

[Sample 1, see p. 94 for section.]

	Coal (air dried).	Coal as received).	Coal (moisture free).	Coal (moisture and ash free).
Moisture.....per cent..	2.7	8.4	.....	.....
Volatile matter.....do....	41.3	38.9	42.5	45.2
Fixed carbon.....do....	50.4	47.4	51.7	54.8
Ash.....do....	5.6	5.3	5.8	.....

Air-dry loss 6.2 per cent.

BROWN BEAR BED.

[Sample 2, see p. 94 for section.]

	2.7	7.0	.....	.....
Moisture.....per cent..	2.7	7.0	.....	.....
Volatile matter.....do....	42.5	40.6	43.7	45.1
Fixed carbon.....do....	50.8	48.6	52.2	54.5
Ash.....do....	4.0	3.8	4.1	.....

Air-dry loss 4.6 per cent.

BOISE BED.

[Sample 3.]

	3.5	9.1	.....	.....
Moisture.....per cent..	3.5	9.1	.....	.....
Volatile matter.....do....	42.1	39.7	43.7	45.1
Fixed carbon.....do....	51.4	48.5	53.3	54.9
Ash.....do....	2.9	2.7	3.0	.....

Air-dry loss 6.1 per cent.

MINING.

HISTORY.

During the year 1901, William Hill discovered coal in the Horseshoe Basin at what is now known as the Horseshoe coal mine. The Mormon tunnel was driven at the Horseshoe mine when Mr. Hill was in charge of the work. The tunnel was abandoned during the year 1904, and remained idle until June, 1916, when the Horseshoe mine was consolidated with the Brown Bear mine. During the summer of 1916 and until the summer of 1917 development work was continued on the Horseshoe mine, but was discontinued during July, 1917. The Brown Bear mine was opened in 1905 and has been worked continuously in a small way since that time. About 25,000 tons of coal have been shipped. The selling price for the coal at the mine in October, 1917, was: Lump coal, \$4 a ton; run of mine, \$3.

The extent of the workings at the Brown Bear mine is shown in figure 3 (p. 93). The mine does not produce much water, and for that reason the pump is run only during parts of the day.

GASES.

No doubt gas will be encountered in mining below the water level in this field. This is a factor that must be considered in planning development work.

METHOD OF WORKING.

In the upper level the coal has all been mined above the level of the gangway, and judging from the statements made, a modified longwall method was used. All that remains of the coal exposed above water level is a few stumps left next to the gangway.

LONGWALL SYSTEM.

As just stated, a modified longwall system has been used in working the Brown Bear bed, and it is probable this system might be effectively used in further working of this bed. The frequency of the faults, however, will prevent a continuous longwall face, so that a modified longwall system to offset the faulting would have to be adopted.

PILLAR-AND-CHUTES OR PILLAR-AND-BREASTS.

There is no reason why a system similar to that used in western Washington could not be used in working these beds, provided it is found that the longwall system is not practicable. By driving narrow chutes 8 or 10 feet wide up the pitch from the gangway at intervals of 40 or 50 feet, center to center, when the upper limit of the chutes is reached the pillars can be removed immediately or can be left standing and removed at a later date.

Where the roof is solid and sufficiently firm, breasts 20 or 30 feet wide, with 30-foot pillars between, could, no doubt, be used effectively. The pillars could be removed after the breasts have reached their upper limit, or could remain standing and be removed when this part of the mine is ready to be abandoned.

In both the pillar-and-chute and pillar-and-breast system, crosscuts connecting the chutes or breasts at intervals of 40 to 60 feet could be used, and in this manner an approved system of ventilation put into effect. A well-constructed airway should be driven through to the surface. The working faces should be connected to this airway by means of crosscuts, and the air should travel down the slope, through the gangway, up through the workings, and continue along the working faces and to the return airway, thence up to the surface.

EQUIPMENT.

At present the power equipment comprises a 30-horsepower Nagel horizontal tubular boiler, steam pressure 125 pounds, and a 25-horsepower steam engine with friction drive. The buildings include a small blacksmith shop for light forging and tool sharpening, the engine room, the boiler room, and blacksmith shop, and sheds to cover the top of the slope.

MANAGEMENT.

On this property, as well as on all other coal properties in districts where the beds are faulted and pitching at considerable angles, management is a very important factor. It is much more difficult to obtain the best results in a field of this kind than in a field where the beds are flat and where the coal is considerably thicker than within this field. In developing and operating this district, the men in charge should have a detailed knowledge of the engineering problems, and also the mining problems that confront a manager in a field of this character. Their training must necessarily have been obtained in coal districts where the beds were faulted and pitching at considerable angles. It would be fatal to the district to have men in charge who are not thoroughly familiar with coal-mining operations.

MARKET.

The coal from this district is of as good quality as the coal mined in either Utah or the Kemmerer field of Wyoming. There is no reason why the lump coal produced here should not demand as high a price as the coals mentioned.

The table following shows the amounts of coal consumed at various points in Idaho and the prices received for the several sizes. These prices were in force in October, 1917. This table has been compiled from data received from the chambers of commerce of the various towns indicated in the first column of the table. The amounts of coal indicated, and also the prices, were submitted at the same time.

It is variously estimated that a market for 100,000 to 200,000 tons of coal yearly could be supplied by this district in direct competition with the Kemmerer field of Wyoming and the Castlegate field of Utah, provided the freight rate from this district to the larger towns of southeastern Idaho and Montana were proportionate to the distances from the several fields.

Data on Idaho coals.

TABLE SHOWING AMOUNTS, PRICES, AND GRADES OF COAL USED BY DISTRICTS IN IDAHO PER YEAR.

District, city or town.	Amount of coal consumed per year.					Price per ton for—			Proportion of—		
	Name of coal.	Lump.	Nut.	Steam.	Tota'. Tons.	Lump.	Nut.	Steam.	Lump.	Nut.	Steam.
Shoshone a.	Utah.....	Tons. 1,800	Tons. 200	Tons. 2,000	Tons. 2,000	\$7.65	\$4.65		Per cent. 90	Per cent. 10	Per cent.
Do.....	Wyoming.....	1,800	200	2,000	2,000	7.50	6.50		90	10	.....
St. Anthony b.	Utah.....	15,500	2,583	5,160	23,243	7.95	7.70	\$5.90	67	11	22
Rexburg c.	Spring Canyon, Hiawatha, etc.....	8,000	1,600	6,400	16,000	9.75	9.50	7.50	50	10	40
Idaho Falls d.	Hiawatha, King, etc.....	26,751	8,584	34,335	34,335				45	25	.....
Blackfoot e.	Utah.....	11,000	3,000	10,000	24,000	3.00	3.00	2.75	46	12	42
American Falls f.	do.....	3,000	600	400	4,000	9.00	8.00	8.00	75	15	10
Do.....	Wyoming.....	1,000	.....	.....	1,000	9.00	.....		100	.....	.....
Boise g.	Rock Springs.....	.....	.....	.....	.....	10.00	9.50	9.00			.....
.....	Kammerer.....	.....	.....	.....	.....	10.00	9.50	9.00			.....
.....	Castlegate, Utah.....	.....	.....	.....	.....	10.00	9.50	9.00			.....
.....	Lyon, Utah.....	.....	.....	.....	.....	10.00	9.50	9.00			.....
.....	Aberdeen, Utah.....	.....	.....	.....	.....	10.00	9.50	9.00			.....
	Total of all Boise coals.....	.....	.....	.....	453,810	10.00	9.50	9.00			.....

- ^a Includes village of Shoshone and tributary territory.
^b Includes territory surrounding Thornton, Rexburg, Sugar City, St. Anthony, Chester, and Ashton.
^c Includes Rexburg and vicinity.
^d No area stated. Grades of coal are: King, Hiawatha, Rock Springs, and Castlegate.
^e Includes Blackfoot and all farming country tributary.
^f Includes Power County.
^g Includes all southern Idaho west and north of Pocatello.

FREIGHT RATES.

The first table following is compiled from data obtained from the freight departments of the Oregon Short Line Railroad Co., showing the freight rates from the Utah and Wyoming coal fields to various points in Idaho and also to Dillon, Mont. Comparison of these rates with the freight rates indicated in the second table following, which shows the rates from Driggs, Idaho, to several of the points mentioned in the first table, shows that the rate per ton-mile is considerably higher from Driggs than from the Castlegate field in Utah and the Kemmerer field in Wyoming.

Freight rates on coal into points in Idaho.

From—	To—	Route.	Distance in miles.	Rate per ton of 2,000 pounds.				Rate per ton-mile.			
				Lump.	Nut.	Slack.	Miscella- neous.	Lump.	Nut.	Slack.	Miscella- neous.
Castlegate, Utah.....	Pocatello, Idaho.....	Denver & Rio Grande and Oregon Short Line.	281.6	\$2.40	\$2.40	\$2.15	\$2.40	\$0.0085	\$0.0085	\$0.0076	\$0.0085
	Blackfoot, Idaho.....	do.....	305.6	2.90	2.80	2.40	2.90	.0004	.0091	.0078	.0004
	Idaho Falls, Idaho.....	do.....	331.5	3.05	2.80	2.65	3.05	.0092	.0094	.0079	.0092
	Driggs, Idaho.....	do.....	420.2	4.90	4.40	4.15	4.90	.0119	.0105	.0068	.0119
	American Falls, Idaho.....	do.....	406.7	2.90	2.90	2.40	2.90	.0071	.0071	.0069	.0071
Kammerer, Wyo.....	Boise, Idaho.....	do.....	545.9	3.90	3.40	3.15	3.90	.0071	.0062	.0058	.0071
	Dillon, Mont.....	do.....	474.7	3.05	3.05	3.05	3.05	.0064	.0064	.0064	.0064
	Pocatello, Idaho.....	Oregon Short Line.	174.5	2.15	2.15	1.90	2.15	.0123	.0128	.0109	.0123
	Blackfoot, Idaho.....	do.....	198.5	2.65	2.55	2.15	2.65	.0133	.0128	.0158	.0133
	Idaho Falls, Idaho.....	do.....	244.4	2.80	2.55	2.40	2.80	.0414	.0104	.0068	.0114
	Driggs, Idaho.....	do.....	313.1	4.65	4.15	3.90	4.65	.0146	.0132	.0124	.0146
	American Falls, Idaho.....	do.....	190.6	2.65	2.65	2.15	2.65	.0132	.0132	.0107	.0132
	Boise, Idaho.....	do.....	438.8	3.65	3.15	2.90	3.65	.0083	.0071	.0066	.0083
	Dillon, Mont.....	do.....	367.6	2.80	2.80	2.80	2.80	.0076	.0076	.0076	.0076

Freight rates on coal from Driggs, Idaho, to points in Idaho and Montana.

From—	To—	Distance in miles.	Rate per ton of 2,000 pounds.	Rate per ton-mile.
Driggs, Idaho.....	St. Anthony, Idaho.....	79.2	\$1.65	\$0.0208
	Rexburg, Idaho.....	62.0	1.65	.0266
	Idaho Falls, Idaho.....	88.7	2.15	.0242
	Pocatello, Idaho.....	138.6	2.15	.0155
	American Falls, Idaho.....	126.7	2.65	.0194
	Shoshone, Idaho.....	246.1	3.40	.0138
	Halley, Idaho.....	303.3	3.65	.0120
	Boise, Idaho.....	402.9	3.65	.0080
	Butte, Mont.....	300.8	2.80	.0093
	Dillon, Mont.....	231.9	2.80	.0120

TRANSPORTATION.

The district is connected with the railroad by means of a poorly constructed wagon road and the freight rate is \$4 a ton both winter and summer (1917). With this excessive freight rate it would be impossible for the coal from this district to compete with other coals at any great distance from Driggs, but with different means of transporting the coal from the mine to the railroad the freight rate could be reduced, and in this way the coal could then reach out to more distant markets.

It might be well before a railroad is constructed into this district to improve the present road; in fact, to build a new road on the right-hand bank of Horseshoe Creek and establish a uniform grade from the mouth of the canyon to the coal mine. By using engines of the caterpillar tractor type, trains of wagons of proper design could be hauled during the summer months from the mine to the railroad, and during the winter months when snow is on the ground runners could be placed under these wagons instead of wheels. In this manner the freight rate could be materially reduced, the field could be more thoroughly developed, and a definite mineable tonnage blocked out.

CONCLUSION.

It is believed that the coal in this field could be mined as cheaply as the coals in the Pierce County coal districts in the State of Washington, and that, because of its location, it should supply a definite yearly tonnage to a part of southeastern Idaho. With proper management, this coal should be sold at a less price than the coal now being supplied to the cities tributary to this district. Also, the supply would be more certain, as the haul would be shorter from Driggs to several of the cities and the grade would be in favor of the loaded train.

In conclusion, therefore, the writer believes that this district should receive serious consideration from men who, by reason of practical experience, are competent managers, and who have sufficient financial backing to open and develop a coal district of this character.

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BUREAU OF MINES

H. FOSTER BAIN, DIRECTOR

**COAL-DUST EXPLOSION TESTS IN THE
EXPERIMENTAL MINE
1913 TO 1918, INCLUSIVE**

BY

**GEORGE S. RICE, L. M. JONES, W. L. EGY,
and H. P. GREENWALD**



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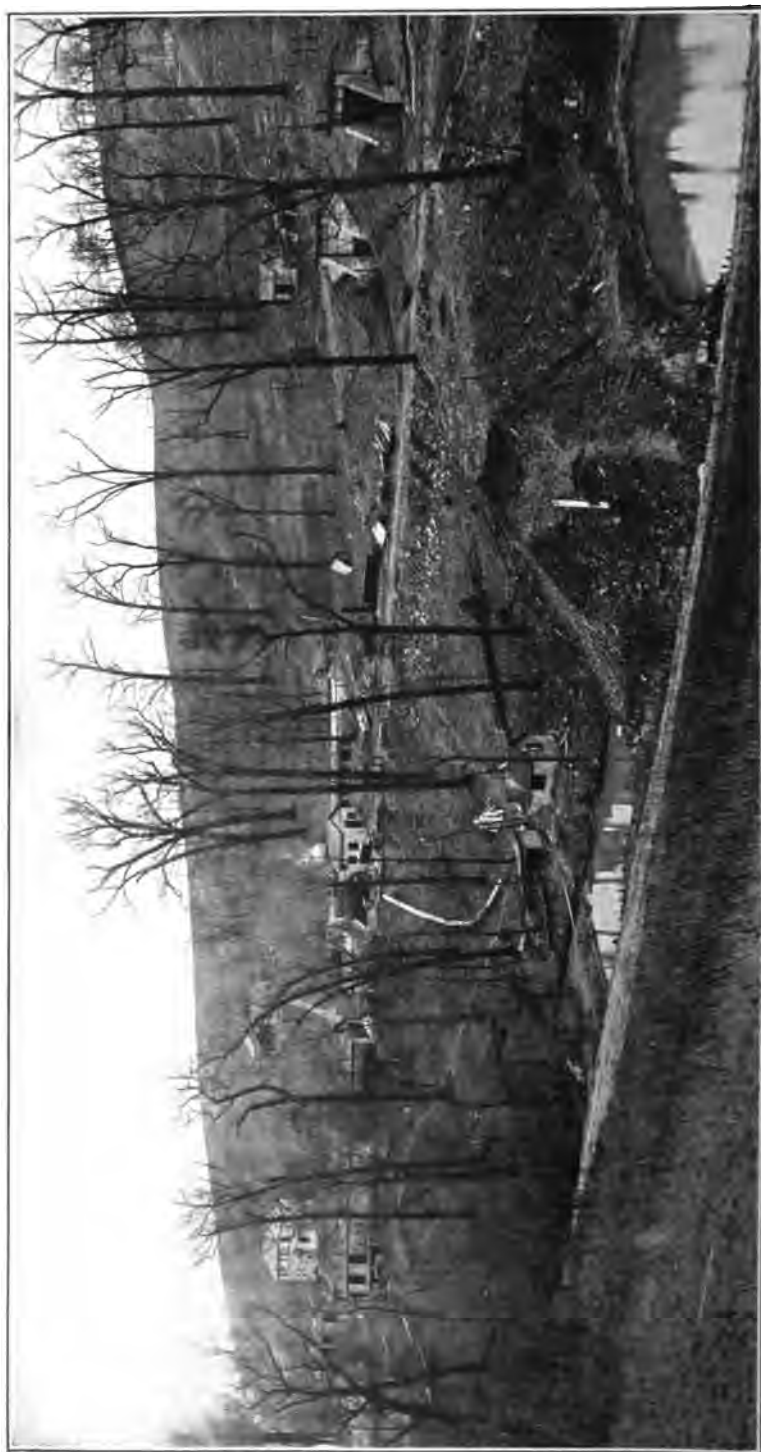
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VIEW OF SITE OF EXPERIMENTAL MINE FROM OPPOSITE HILLSIDE.

COAL-DUST EXPLOSION TESTS IN THE EXPERIMENTAL MINE.

By **GEORGE S. RICE** **L. M. JONES**, **W. L. EGY**, and **H. P. GREENWALD**.

CHAPTER I.—INTRODUCTION AND SUMMARY.

By **GEORGE S. RICE**.

PREFATORY STATEMENT.

This bulletin describes the second series of coal-dust explosion tests conducted by the Bureau of Mines in the experimental mine near Bruceton, Pa. It covers a period from 1913 to 1918, inclusive, of more or less consecutive testing, during which many important conclusions were drawn regarding the way a coal-dust explosion may originate, the mechanism of an explosion, and the methods of preventing explosions and of limiting incipient explosions.

The manuscript was prepared in 1918, but its publication had to be put aside during the World War for more pressing publications and it was not until this fiscal year 1922 that funds could be allotted for its printing. Meantime the general facts concerning methods of preventing explosions have been made known to the mining industry, with great advantage, it is believed, as explosions of coal dust in mines in the United States have become infrequent. This fact, however, must not lull the consciousness of mining men to the terrible potential danger that lurks in untreated coal dust. The experiments described in this volume should be of aid to them in planning to keep the ever present coal dust in an innocuous condition.

The first series—reported in Bulletin 56, "First Series of Coal-Dust Explosion Tests in the Experimental Mine"—included only preliminary tests of the ability to start explosions of coal dust under the conditions in the experimental mine. After this fact had been determined and several violent dust explosions had been demonstrated before large audiences of mining men, the work had to be suspended in order that necessary repairs and extensions might be made in the fall and winter of 1911-12.

Although the question of the possibility of coal dust causing explosions had been considered for more than a century, and much testing in laboratory apparatus and in small surface galleries had been done,

coal-mining men generally did not believe that coal dust was explosive and considered that fire damp or gases of unknown composition were responsible for the mine explosions that had cost thousands of lives in the various coal-mining countries during the last century.

As coal mines increased in number, size, and depth, explosions became alarming in their frequency. Finally came the Courrières disaster in northern France, 1906, by which 1,100 lives were lost, and the following year in this country, the Monongah mine explosion, in West Virginia, which killed 361 men, and the Darr explosion, in Pennsylvania, which killed 239 men. These two disasters, both in December, 1907, led Congress to make an appropriation for an investigation of the causes of mine explosions. The funds became available July 1, 1908, and the work was placed under the United States Geological Survey's technologic branch, with the late Dr. Joseph A. Holmes in charge.

Before undertaking the investigations Dr. Holmes visited Europe, accompanied by the senior author of this bulletin, to study the methods foreign countries used to prevent mine explosions, to obtain details regarding tests being made in several countries, to procure safer explosives and better safety lamps for use in gaseous and dusty mines, and to study the methods used in coal-dust explosion tests in the recently completed galleries at Altofts, England, and Liévin, France, and in the older galleries at Gelsenkirchen, Germany, and Frameries, Belgium. At all of these stations the explosions tests were made in surface galleries.

The Austrian gallery at Segengottes, near Brünn, Moravia, visited by the writer in 1911, is an underground gallery, but the testing done in it was limited, dealing with ignition of coal dust rather than with propagation.

Although the results obtained in the foreign galleries had indicated that coal dust was explosive, mining men in the respective countries were of the opinion that the dust would not explode under mine conditions. This situation led Dr. Holmes to the conclusion that testing must be done in a real mine, to make certain that the conclusion would be reliable and would be accepted by the mining public as decisive.

While awaiting the opportunity to make such tests, Dr. Holmes had erected at Pittsburgh, Pa., in the latter part of 1908, a 100-foot steel gallery to test the relative safety of explosives, and some preliminary tests of the explosibility of coal dust in air were made there. When Congress established the Bureau of Mines (July 1, 1910), the bureau took over the work of the technologic branch of the United States Geological Survey, Dr. Holmes being appointed the first director. Shortly thereafter Dr. Holmes approved the plan of obtaining a mine for investigating the causes and prevention of

coal-dust explosions. The following year, after unsuccessful search for a suitable existing mine, a site for an experimental mine near Bruceton, Pa., was selected and underground entries were started.

The first 15 experimental explosions were conducted during the fall of 1911 and the winter of 1912, as described in Bulletin 56. The destruction resulting from two of these explosions was so great that the cost of the extensive repairs necessary in rehabilitating the mine prevented further tests during the fiscal year. However, these early tests made a decided impression on the public. In fact the turning point in the attitude of the coal-mining men began with these violent explosions, which demonstrated to the mining audience that dry coal dust was an exceedingly dangerous thing in a mine, even without the presence of inflammable gas in the air.

The cost of the experimental mine and of the tests conducted therein has been great. The expenditures since 1911 have directly and indirectly averaged about \$30,000 a year. The total expenditure during the eight years 1911 to 1918, inclusive, was approximately \$240,000. Of this amount, about \$100,000 is invested in the mine, buildings, and equipment.

In the United States alone, during the 10 years 1901 to 1910, there were in bituminous and subbituminous mines 106 gas and dust explosions that killed five or more men. This total does not include explosions of powder or dynamite that did not ignite gas or dust; nor does it include anthracite mine explosions, as these were of gas alone and hence local in effect. Tests have demonstrated that anthracite dust would not propagate an explosion. It is not possible to discriminate between gas explosions and dust explosions at bituminous mines.

In these 106 explosions 3,296 men were killed. After the demonstrations in the experimental mine of the explosibility of bituminous dust, beginning in 1911, the extent of bituminous mine explosions declined. In the ten years 1911 to 1920, 75 explosions occurred in mines in which five or more men were killed, with a total number of 2,057 deaths, a reduction of 1,239 in number killed as compared with the preceding 10 years, although the average number of miners and the average production had increased nearly one-half.

The most encouraging feature is that in the last three years, 1918, 1919, and 1920, the deaths from explosions in which five or more men have been killed have been only 41, 81, and 47, respectively. In explosions killing less than five men it is considered that there was no extended propagation of a local explosion of gas or local coal-dust ignition by a blown-out shot, indicating the more general use of methods of immunizing coal dust by watering, humidifying, or by dilution by rock or shale dusting.

In addition to the reduction in loss of life, an appreciable saving in dollars and cents was undoubtedly effected, because the cost of repairing and restoring a large mine after a disastrous explosion has been more than half a million dollars, apart from the compensation paid for lives lost and the losses in business during the restoration of the mine, which sometimes has required a year.

This reduction of expenditures and loss of life are of course not claimed to be directly due to the investigations at the experimental mine; these tests were only a part of a general campaign for safer conditions in mines, in which the operators and miners cooperated with the bureau. Unquestionably, however, the findings obtained in the experimental mine have had a most important influence on the methods adopted by State inspectors, operators, and miners, and have brought home to them dangers that had been overlooked.

ORGANIZATION AND ACKNOWLEDGMENTS.

After the death of the first director of the Bureau of Mines, a man of great vision and the highest humanitarian ideals, the investigations at the experimental mine received the constant support of his successor, Dr. Van H. Manning.

In carrying on the work at the experimental mine, the bureau has continued to be indebted to the Pittsburgh Coal Co. and its officials, Mr. F. E. Field, president, and Mr. G. W. Schleuderberg, general manager (now deceased), and their assistants, for the use of the coal land and adjacent surface at a nominal consideration and for their sympathetic attitude toward the work being done.

This investigation has been greatly aided by the parallel work conducted by foreign coal-dust experiment stations, especially by that of France at Lièvin and of Great Britain at Eskmeals. The reports of the studies made by Mr. J. Taffanel, director of the French station, on the principles involved in mine explosions have been of the greatest value. Although the first shale-dust arresting barriers devised by Mr. Taffanel did not prove effective under all conditions at Bruceton, their trial in the testing work yielded suggestions that aided in the development of the special forms of dust barriers planned by the writer. The visit of Mr. Taffanel to the experimental mine in May, 1914, to observe the methods of testing was particularly encouraging, and many valuable suggestions were made by him.

The work as organized was from its inception under the charge of the senior author, assisted by L. M. Jones, a mining engineer of exceptional ability who lost his life October 20, 1916, in rescue work following an explosion in a mine at Barrickville, W. Va., an explosion that resulted in the death of ten men. W. L. Egy, physicist, had charge of the instrument work and measurements of the second series of tests, and after the death of Mr. Jones, had general charge of the

mine. The successful designing of the new instruments for obtaining satisfactory records in the explosion testing was chiefly due to his skill and effort. H. P. Greenwald, assistant physicist, who was placed in immediate charge of the instrument work after Mr. Egy succeeded Mr. Jones, showed unusual ability in handling these instruments of great delicacy and precision and in interpreting the records of instruments. Special thanks are due Mr. Greenwald for assembling data, preparing charts and diagrams in this bulletin, and reviewing the manuscript for publication. Dr. J. K. Clement, physicist in charge during the first series of tests, gave much assistance at the beginning of the second series. Alan Leighton, assistant chemist, has aided greatly by his advice. H. C. Howarth, foreman and later superintendent of the mine, had charge of the miners, laborers, and machinery. He has shown great skill in keeping the mine in suitable condition and in preparing it for tests.

A. C. Fieldner, in charge of the chemical laboratory at the Pittsburgh station, has aided in the extensive chemical work necessary in connection with every test, has given valuable advice regarding chemical factors in the testing, and in addition has controlled the extensive routine analytical work required. G. A. Burrell, formerly in charge of gas chemistry for the Bureau of Mines, greatly assisted in the work by interpreting results of analyses of mine air and gases gathered by the automatic samplers in the course of an explosion and by helping develop the automatic apparatus for gas sampling. J. W. Paul, formerly in charge of mine rescue work of the Bureau of Mines and now chief of coal-mine investigations, has at all times given valuable counsel. W. F. Hausstein, foreman instrument maker, has made many valuable suggestions regarding the design and construction of instruments used in the testing. The other persons, both members and nonmembers of the bureau, who have helped to conduct the investigations are so many that it would be difficult to name all of them.

CHIEF RESULTS.

The chief results of the second series of the tests may be summarized as follows:

1. Control of ignition and propagation factors in coal-dust explosion testing was effected.

2. Methods were developed for determining the velocity of flame, duration of flame, and pressure at a given point, and for obtaining simultaneously the vibrations and amplitude of the pressure waves of coal-dust explosions.

3. Satisfactory explosion-testing instruments were selected and developed, especially the chronograph for registering time; sensitive pressure manometers with negligible inertia of moving parts and suitable arrangement for recording photographically the passage

of flame; registration of passage of flame (by fusing of tin-foil) at successive stations, permitting determination of velocity at points where there are no Bureau of Mines manometers; automatic samplers, with definite times of opening and with positive closing arrangements, thus permitting the obtaining of samples of burning gases and afterdamp at any prearranged intervals of time.

4. The tests showed the ineffectiveness of so-called dustless zones in a dry coal mine, of watered or wet zones in stopping an explosion if there is any dry dust present on the ribs or timbers, and of the inefficiency of merely moistening the dust as a preventive of explosions and the necessity of wetting the dust thoroughly to prevent an explosion.

5. The tests established the ability to limit the violence of explosions or to extinguish them by admixtures of shale dust or limestone dust. As a corollary, methods were devised for determining the explosibility limits of coal dust, both in pure air and in air mixed with inflammable gas, on the basis of the proportions of shale or inert dust gradually added until the mixture is no longer explosive in pure air, or in air containing 1, 2, or 3 per cent of natural gas.

6. The flame of explosions can be checked or extinguished at any prearranged point by employing rock-dust barriers of several types. Tests were made of the efficiency of various types of barriers for limiting explosions (which may originate in spite of other precautions) to a pair of entries or a zone in the entries, and preventing widespread destruction and loss of life. In numerous instances in disastrous explosions investigated by the bureau such barriers would have reduced greatly the loss of life.

7. Thoroughly successful types of mechanically operated rock-dust barriers were developed, including special combinations for use at cut-through stoppings, ventilating doors, and overcasts, thus dividing a mine into protected sections.

8. Standard methods were evolved for testing the explosibility of different sizes and kinds of coal dusts and coal dust mixed with mine shale and rock dusts.

9. The sizes of coal dust and the character of the roof, partings, and floor particles mixed with it, as found in the passageways of mines in different coal fields of the country, were determined with a view to duplicating these conditions for explosion testing in the experimental mine, in order to decide the so-called "explosion hazard" of the respective mines.

10. The velocity and direction of the ventilating current have no effect on the occurrence of ignition where dust is inflammable; nor do these prior conditions of the ventilating current affect the direction or path of an explosion. However, the danger of raising a dust cloud

by firing in quick succession several near-by heavy blasts either in a strong ventilating current or in still air should not be minimized, because a premade coal-dust cloud increases greatly the chances of ignition from a flame of any sort.

11. A saturated condition of the mine atmosphere has no appreciable effect on the liability of ignition of coal dust in air and on the propagation of flame through the dust cloud. This statement refers to the saturated water vapor in the air prior to the explosion and not to the gradual moistening of the dust through maintenance of a super-saturated atmosphere for a long period. The quantity of heat absorbed by saturated water vapor is insignificant compared to the heat from combustion of coal dust in a unit volume of air.

12. The all-important fundamental factor in the propagation of a coal-dust explosion is the presence of a small amount (0.05 ounce or more) of coal dust per cubic foot of air space.

13. Pulverized coal dusts (75 per cent through a 200-mesh screen) from different coal beds are sensitive in direct proportion to the percentage of volatile combustible matter that the dusts contain, and in inverse proportion to their content of water and ash. Pure anthracite dust in air will not ignite and propagate an explosion in itself, whereas dry subbituminous coal dust is one of the dusts most sensitive to ignition. Pittsburgh pulverized coal dust has practically the same explosive limits as lignite dust; in other words, the finest size of Pittsburgh coal dust is one of the most dangerous dusts for ignition and propagation. In order to prevent the propagation of an explosion through Pittsburgh coal dust in air, an admixture of 75 per cent of inert matter is required and if 1 and 2 per cent of fire damp is present in the atmosphere 5 and 10 per cent more of inert matter will be needed to prevent propagation. The inherent ash and moisture of the coal are included in these figures.

14. Artificial pulverizing of coal disrupts and destroys its natural structure. In some coals the cleavage is somewhat cubical, and such coals often do not naturally break into exceedingly fine particles like others, such as the New River and Pocahontas "smokeless" coals. The behavior of the naturally made coal dust (mine dust), containing, as it does, larger sizes of particles, proved different from that of the pulverized dust of the same coal. This difference led to field investigations to determine the average size of the dust from each mine, so that as far as possible the size could be duplicated in testing the dust at the experimental mine.

15. The difference in behavior of the natural dusts was due largely to the variation in the percentage of the finest dust present; that part passing through a 200-mesh screen was found to be the best index. The coarsest dust that took any part in the initiation of an explosion

was indicated to be below 20-mesh size, confirming the results of earlier testing at the Pittsburgh gallery.¹

16. It was found that most mine road dust (considering that portion passing through a 20-mesh screen) contained not more than 10 to 20 per cent by weight of particles that would pass through a 200-mesh screen. Rib and timber dust were found to contain about 40 per cent of dust that would pass through a 200-mesh screen. In contrast with this, 75 per cent of the pulverized dust, pulverized by commercial grinders or mills, would pass through a 200-mesh screen.

(a) In testing 20-mesh Pittsburgh "road dust" of which 10 per cent passes through a 200-mesh screen it was found that the explosive limit in air was lowered from 75 per cent—as compared with the standard testing dust used at the experimental mine—to 55 per cent incombustible, or the addition of about 50 per cent of shale dust was needed in order to make it inert. That is to say, when an equal amount of shale dust is present with this size of coal dust, the mixture will not propagate an explosion.

(b) For the 20-mesh road dust of which 20 per cent would pass through a 200-mesh screen the explosibility limit is raised to a little more than 60 per cent of incombustible matter.

(c) For the 20-mesh rib or timber dust of which 40 per cent passes through a 200-mesh screen the explosibility limit of the most sensitive kinds of dust is as high as 70 per cent of incombustible matter. Hence, in order to make such dust inert, so that it will not propagate an explosion, twice its weight of shale dust must be mixed or be present with the coal dust. These limits are somewhat higher than those determined in the tests conducted in the British surface gallery at Eskmeals, but the conditions in mine passages may be more severe than those of a surface gallery.

17. The presence of inflammable gas in proportions smaller than 3 per cent proved to have less effect than was expected in raising the explosibility limits of the coal dust. Approximately 5 per cent more shale dust will neutralize 1 per cent of gas, and 10 per cent more shale dust will neutralize about 2 per cent of gas.

18. It was determined that in order to prevent ignition or propagation by introducing shale dust in an amount equal to or ranging up to twice the amount of coal dust, the shale need not be mixed mechanically with the coal dust. The advance air waves raising the coal dust into suspension likewise raised the shale dust, thus automatically mixing them in the air, and the result is the same as if the mixing were done beforehand. Naturally, however, it is safer to have the shale dust as the top layer.

¹ Rice, G. S., *The explosibility of coal dust*, with chapters by J. C. W. Fraser, Axel Larsen, Frank Haas, and Carl Scholz; Bull. 20, Bureau of Mines, 1911, pp. 42-45.

19. The zone of flame in a rapidly moving explosion is comparatively short (the duration of the flame ranges from 0.03 to 0.1 second); a minimum length of 50 feet or even less has been indicated, although in some tests the flame may be several times this length. The forefront of the flame is of a blunt wedge shape; thus an explosion as it traverses a passageway proceeds centrally and burns toward the ribs, roof, and floor.

20. When an excess of coal dust is present the flame does not always reach the walls of the passage, as under such conditions no photographs of the flame are registered through the small plate-glass windows of the recording apparatus. The reason is that an impenetrable cloud of dust skirts the walls of the passageway; this explains why, in many explosions, combustible material along the walls shows no evidence of burning. This assumption is further confirmed by the fact that gas samples gathered by automatic samplers placed centrally differ markedly from those obtained by the samplers at the walls, both sets of samples being taken at the same time, and in or immediately following the combustion zone of the explosion. In some tests the sample gathered by a centrally placed sampler may show less than 2 per cent of oxygen, whereas the sample obtained simultaneously at the wall may show 10 to 18 per cent.

21. The flame of the most rapid explosion registered in the experimental mine attained a velocity of about 6,000 feet a second, which is much faster than black powder burns and approaches the velocity of detonation of some of the slower detonating explosives.

22. Testing indicated that a coal-dust explosion, like a gas explosion, proceeds through the combustible mixture at the speed of a sound wave in heated gas; at the same time the air and dust mixture as a zone is advancing en masse, or rarely, is retrograding. Hence the total velocity of an explosion with reference to the wall of a passageway is the algebraic sum of the velocities of the column of burning gas and of a sound wave in heated gas.

23. When an explosion is increasing in violence it sends off pressure waves that travel back toward the region just traversed and through the burning gases at the rate a sound wave travels through heated gases (the rate being proportionate to the temperature of the gases), so that at a point toward the origin the pressure may be higher than it was at the earlier moment when the explosion flame passed. These return pressure waves have been termed retonation waves; they should not be confused with suction or depression waves, which are below the atmospheric pressure line and are caused by a partial vacuum resulting from the cooling of the gases and the condensation of steam.

24. The maximum depression registered below atmospheric pressure was about 9 pounds per square inch, but as a rule not more than 6

pounds has been registered. The effect of the depression is to produce return waves only after the explosion has passed.

FUTURE WORK.

Although a large amount of information regarding the underlying factors as to the starting propagation, limitation, and prevention of coal-dust explosions has been obtained in the 494 explosion tests in the experimental mine up to May 22, 1918, the investigation is far from completed. During the war the work was laid aside in favor of certain military problems relating to underground sound detection and sound ranging and tests of military explosives. Since the signing of the armistice the investigations made at the mine have related to explosion hazards. Problems that are unfinished or require the gathering of more evidence or have not yet begun are as follows:

1. Determination of the best method of preventing coal dust from igniting. It is assumed that the production of coal dust in workings can not be prevented, nor can the sources of ignition—such as the flame of explosives, electric short circuits or arcing, and flames of a fire or of a miner's lamp—be entirely eliminated.

2. Determination of the best method of making coal dust inert—in order to prevent propagation if an accidental preliminary explosion of new dust or of fire damp takes place—by using the watering method or the dry method, rock dusting, or a combination of the two methods.

3. The determination of what positions of a shot or shots in the face of entries or rooms or in brushing are most likely, or least likely, to cause ignitions of coal dust—the position of the shot to be varied with reference to the plane impinging on floor or ribs, and the quantity, position, and distribution of the coal dust to be varied with reference to the shot or shots.

4. The effect of increasing the charge of a shot and the effect of more than one shot in changing the ignition limits of the dust.

- 5^a. An estimation of conditions governing the starting of an explosion in a room or wide place, in comparison with the starting of an explosion in a narrow place or entry. The tests already made indicate that with the same quantity of coal dust per unit of space and the same size of igniting charge an explosion is not as easily started in a room; however, in many districts the custom of firing several large shots in one room at the same time or in quick succession changes the conditions and brings about vibratory effects.

- 5^b. The determination of the percentage of incombustible matter necessary to prevent ignition in wide places or rooms.

6. Further investigation of the desirability of having weak or strong stoppings. The rupture of weak stoppings near the origin of an incipient explosion may tend to relieve the pressure and thus make propagation less likely, whereas, on the other hand, it is possi-

ble that the same action in an operating mine may bring large quantities of coal dust from the cut-throughs into suspension, and thus tend to increase the violence and extent of the explosion.

7. Further testing of dusts from coals with the same ratios of volatile matter to total combustible matter as those already tested, especially coals of the same ratios from different coal districts and coals with other ratios. If the relation so far determined is found to be general, it will be possible to determine, as has already been determined for dusts from many coals, the degree of protection necessary to prevent the coal dust under consideration from exploding under conditions as severe or less severe than the experimental conditions.

8. Further tests to determine the explosibility ratios of the naturally made dusts of different coals for comparison with the pulverized dusts of the same coals. Tests already made indicate that the structure of some coals is such that pulverizing to fine dust changes the explosibility behavior of the dust. This fact is well illustrated by the immunity of subbituminous mines to dust explosions, although dusts made by drying and pulverizing coal from these mines is highly explosive in air.

9. Further tests of rock-dust barriers to determine the desirability of modifications to increase their efficiency or simplify their construction or to develop new kinds for special purposes.

10. The determination of the best materials for rock dusting, the most efficient sizes of dust for various purposes, and the best method of applying the dust.

11. Further tests to determine whether shale dust, unmixed with coal dust but thrown over it, or shale dust covered with a film of coal dust, is efficient in preventing propagation, and what changes of proportions are necessary in consequence.

12. Continuance of experiments with wetted coal dust to confirm the results of the series already made. These latter indicated that pure Pittsburgh pulverized dust required 30 per cent of water in the mixture by weight to prevent its rising into the air and propagating an ignition, and that with shale dust present less water was required. Coarser dust likewise required less water; 20-mesh dust, of which 10 per cent passed through a 200-mesh screen, required only 15 per cent of water to render it inert. More information as to the relative efficiency in practical use of water and of rock dust is desirable.

13. Continued tests of the influence of fire damp on ignition of different kinds of dusts and the propagation of explosions in them.

14. The determination of the distillation of gases from dust prior to combustion, as well as during and after an explosion, by using considerable numbers of the new Bureau of Mines automatic sampler arranged in various groupings.

15. The determination of the degree of heat produced to cause the ignition of dust and the heat attained in propagation. This temperature is very difficult to determine on account of the momentary duration of the flame.

16. Additional studies of the effect of turns and curves in the path of an explosion.

17. The effect on the main explosion of side branching and of local widening of the entry traversed, or the entering of extensive areas of old workings.

18. The physical reactions on propagation of an incipient explosion in an entry on entering another and squarely facing the opposite rib. It has been observed that explosions in the second, butt entry of the experimental mine tended to die away before reaching the air course off which the entry turns at right angles. It is believed that the shock waves, striking squarely on the rib wall, are reflected and tend to neutralize the direct waves of the explosion, checking the forward movement, and thus permitting the dust to drop from the air before the flame reaches it. Such reactions would not be effective where extensive explosion had started before encountering an opposing surface, but can be possible only near the initiating point.

A great field of investigation thus lies open, of which only a part has been explored. The pursuit of some of these investigations in all probability will elicit facts of great interest and value, and may indicate that modification is desirable in the systems used and in those proposed for safeguarding against explosions.

SUMMARY OF PURPOSES OF TESTS AND RESULTS.

REASON FOR ESTABLISHING THE EXPERIMENTAL MINE.

The experimental mine, as previously stated, was opened to make large-scale explosion tests under actual mine conditions. The engineers of the Bureau of Mines believed that although testing in large steel-surface testing-galleries, such as those of Great Britain, Germany, and France (described in Bulletin 20,² Bureau of Mines), gave valuable results, the physical conditions differed in so many ways from those in underground passages that any data obtained and any preventive measure developed by the gallery experiments should be confirmed or modified by actual mine tests.

REVIEW OF THE 15 PRELIMINARY MINE TESTS.

The first explosion tests,³ beginning in October, 1911, when the mine consisted of only a pair of entries 700 feet long, were trials to

² Rice, G. S., *The explosibility of coal dust*, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz, 1911, pp. 149-166.

³ Rice, G. S., and others, *First series of coal-dust explosion tests in the experimental mine*: Bull. 53, Bureau of Mines, 1913, 115 pp.

determine whether coal-dust explosions could be obtained at will under predetermined conditions of testing and to demonstrate to large numbers of mining men the explosibility of coal dust in air containing no fire damp. This latter fact had been demonstrated in surface galleries abroad and was generally regarded as proved, but many practical mining men were still incredulous.

In the first series there were two demonstration tests, as described in Bulletin 56;⁴ these were so violent in character and the arrangements were such that the most skeptical were convinced of the explosibility of coal dust. On account of the wreckage caused by the second explosion several months elapsed before the mine was repaired.

A series of tests followed in which coal dust was distributed through short zones of the mine entries, then through progressively longer zones, in order to study the development of the explosions by recording the flame velocities and the gas pressures at various points, also to try out the recording instruments for future explosion tests. Incident to the preliminary testing so-called "Taffanel" barriers, consisting of 10 open shelves loaded with rock dust for arresting or stopping the explosion, were tested.

SECOND SERIES OF COAL-DUST EXPLOSION TESTS.

Inasmuch as the funds for preliminary testing were exhausted, work was suspended for the fiscal year ended June 30, 1912. During the following summer the mine was enlarged by extending each of the pair of main entries to a length of 1,270 feet and by driving from the main air course a pair of butt entries each 210 feet in length and from the main entry a single butt entry 100 feet long. A plan of the mine is shown in figure 1.

In September, 1912, five tests were made with variant positions of the igniting shot. This series was intended to demonstrate the arrangement of the mine and its suitability for experiments to the International Conference of Mine Experiment Stations, attended by representatives of France, Great Britain, Belgium, Russia, Germany, and Austria. These tests (Nos. 16 to 20, inclusive) are described in detail in Bulletin 82,⁵ which reports the transactions of the conference.

Following this group of tests further improvements were made in the mine and in the arrangements of the instruments. The funds for that fiscal year were then exhausted and explosion testing was postponed until the following year.

METHODS OF WETTING COAL DUST.

Advantage was taken of the suspension of the explosion testing to continue the investigation of methods of moistening coal dust by

⁴ Rice, G. S., work cited, pp. 69, 105.

⁵ Rice, G. S., International Conference of Mine Experiment Stations: Bull. 82, Bureau of Mines, 1914, pp. 43-48.

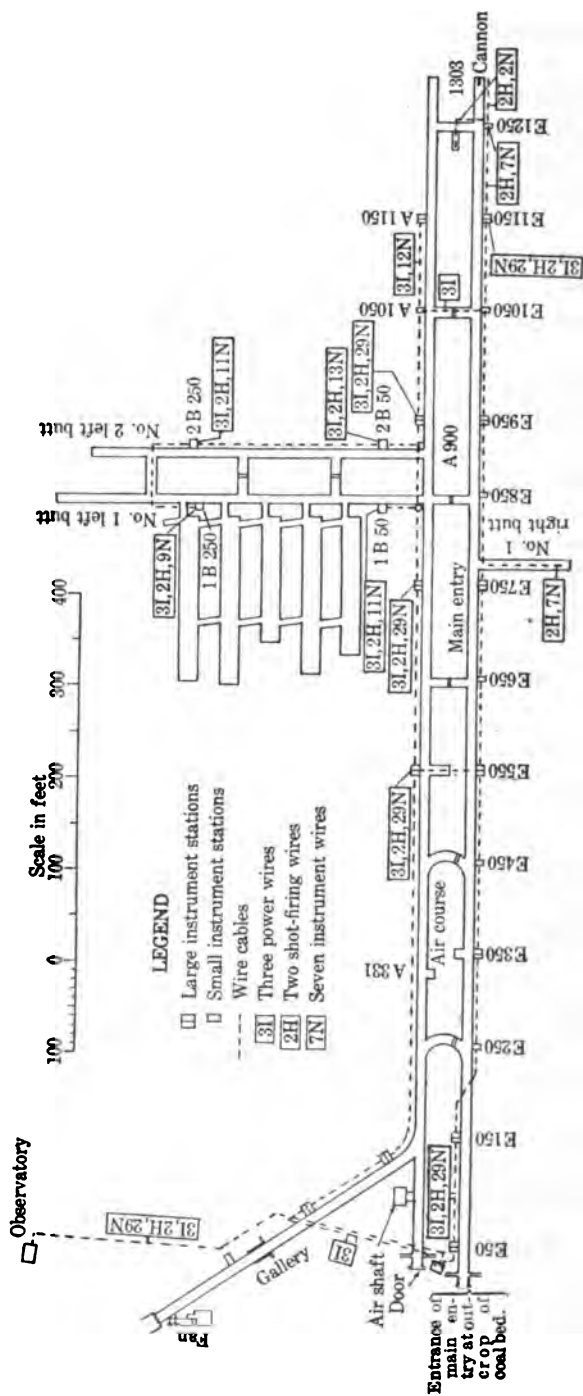


FIGURE 1.—Diagram of experimental mine, observatory, stations, wiring, and development.

sprinkling, by humidifying the intake air, and by the use of deliquescent salts. These investigations were begun at the Pittsburgh gallery in 1908-9, and continued by field tests in mines in various parts of the United States. Reference has been made to them in a publication of the Bureau of Mines.⁶

The results of the humidifying and wetting tests conducted in the experimental mine are briefly described in this report (pp. 401 to 411); a more detailed account will be given in a subsequent report dealing with the whole question.

EFFECT OF HUMID AIR IN MOISTENING COAL DUST.

Tests showed that the moisture content of pure coal dust remains practically the same in a saturated air current and that the dust takes up additional moisture only when swept by supersaturated air. These tests (described on p. 403) indicate that if a mine passage is naturally dry and a method of humidifying the air current to prevent explosions is to be adopted, it will be necessary to supersaturate the air currents throughout the mine; that is, the mine air must be foggy in order to wet the coal dust. As it is impracticable to have such fog throughout a large mine, it will be necessary for the sake of safety in naturally dry mines to supplement humidification of the air current by frequent sprinkling of the dry places. The saturated condition of the air prevents the drying of the dust which would otherwise take place.

TESTS OF CALCIUM CHLORIDE.

In one set of tests with calcium chloride, the dry granulated chloride was spread over the coal dust; in other tests a solution of calcium chloride in water was sprinkled over the dust. In both series of tests water collected in globules and films on the surface, but the dust beneath the surface remained dry. Even when the calcium chloride was mixed with the dust it was possible to shake out the globules which collected around the particles of calcium chloride; an analysis of the dust remaining showed little moisture content, thus demonstrating the difficulty of wetting pure coal dust (see p. 405).

As effective moistening of road dust by calcium chloride has been accomplished in some commercial mines, it is believed that the failure to obtain general wetting of the dust in the tests at the ex-

⁶ Rice, G. S., *The explosibility of coal dust*, with chapters by J. C. W. Fraser, Axel Larsen, Frank Haas, and Carl Scholz: Bull. 20, Bureau of Mines, 1911, pp. 104-107; Rice, G. S., *Coal-dust explosions: Miners' Circular 3*, Bureau of Mines, 1911, pp. 16-20; Rice, G. S., *Notes on the prevention of dust and gas explosions in coal mines*: Tech. Paper 56, Bureau of Mines, 1913, p. 10; Williams, R. Y., *The humidity of mine air, with especial reference to coal mines in Illinois*: Bull. 83, Bureau of Mines, 1914, 89 pp.; Rice, G. S., and Jones, L. M., *Methods of preventing and limiting explosions in coal mines*: Tech. Paper 84, Bureau of Mines, 1915, pp. 10-15.

perimental mine was due to the dust deposits not being stirred up by the passage of trips or by the feet of men or animals, thus mixing the water and dust.

WETTING MIXTURES OF COAL DUST AND ROCK DUST.

In the course of the explosion tests with mixed dusts the important observation was made that when a large proportion of shale or limestone dust was present the mixture quickly became wet if the floor or ribs on which it rested was wet.

This observation suggested the use of rock dust as an aid in wetting coal dust by sprinkling methods, because the mixed dust, once dampened, would not be so difficult to keep damp. Pure coal dust itself is very difficult to wet. Thick layers (one-half inch or more) of coal dust have been observed floating undampened on the surface of pools of water in old workings of mines more than a year after an explosion.

The ease of wetting coal dust proved to be somewhat in proportion to the percentage of shale dust present, a result that was confirmed by laboratory tests (see p. 407). At mines where watering methods are used and the coal dust difficult to wet, scattering shale or other incombustible dust over the surfaces of the entryways should be advantageous in facilitating the wetting of the coal dust.

RESULTS OF SECOND SERIES OF EXPLOSION TESTS.

DETERMINATION OF CONDITIONS FOR EXPLOSION TESTS.

The first undertaking in the second series of coal-dust experiments was to standardize the test conditions in order to obtain, if possible, a controllable starting impulse for the explosions and to be able to obtain duplicate results for similar conditions. This development of standard methods of control was a difficult matter, as compared with gallery testing, because in the beginning the fundamental factors affecting explosions in a mine were not clearly understood, hence many changes were made in arrangements from time to time in attempting to get consistent results. Finally, however, methods of testing were developed that have given satisfactory results, and for the purpose of comparing different coals standardized methods of testing were adopted (p. 66).

TESTS WITH PURE COAL DUST.

In the course of obtaining standard conditions many tests were made with pure Pittsburgh coal dust, and records of flame velocities and of pressures were obtained (see pp. 63, 66). When an ignition is obtained by means of a blown-out shot fired into a zone containing 2 pounds of coal dust per linear foot (0.55 ounce per cubic foot) in one of two connected parallel entries, the explosion starts with low velocity

100 to 200 feet per second, and low pressures of about 5 pounds per square inch; both the velocity and the pressure increase slowly for several hundred feet and then more rapidly until at the end of a zone 350 or more feet long the explosion is traveling at a very high velocity, with great pressures. Pressures of 86 and 119 pounds have been recorded at points 350 and 750 feet from the explosion origin, and flame velocities of more than 3,000 feet per second indicated.

When coal dust is loaded into both entries, the explosion develops much more rapidly. Velocities of 4,000 feet per second and pressures of 127 pounds per square inch have been attained in a distance of 350 feet.

DUSTLESS ZONES.

In a number of tests, zones of definite length with the usual distribution of coal dust had dustless zones outby them (see p. 90). The so-called dustless zones were cleaned by sweeping them with whisk and house brooms and by blowing with compressed-air jets. As the floor was damp clay, well packed, these cleaned zones were probably more nearly dustless than an entry in an operating mine would be after a thorough cleaning. Notwithstanding the practically dustless condition, the flame swept as much as 800 feet through the dustless zone when the explosion was started in a 300-foot coal-dust zone, and more than 500 feet when it was started in a 100-foot coal-dust zone. Such results show that the danger of explosions propagating to great distances can not be wholly eliminated by any method of dust removal only. Removal of the coal dust is not enough; some means of limiting the explosion must also be provided. Wet surfaces tend to limit all explosion, and rock dust in such quantity and so distributed that a strong blast will cause a thick dust cloud to rise gradually extinguishes the flame of an explosion.

MINIMUM QUANTITY OF COAL DUST FOR PROPAGATION.

After the inner 350 feet of both main entries of the experimental mine were concreted, so that thorough cleaning between tests was possible, a number of tests were made to determine the minimum quantity of coal dust necessary to propagate an explosion initiated in a 50-foot zone of pure Pittsburgh pulverized coal dust (see p. 94).

Four tests were made—two with special cross shelves of loose 1-inch boards extending across the entry at 10-foot intervals about 3 feet above the floor and two with only the regular fixed cross shelves about 5 feet 2 inches above the floor. The special shelf arrangement proved the most effective, but not enough tests were made to determine the degree of superiority. In each test propagation was obtained with a 0.3 pound of coal dust per foot of entry, which is equivalent to about 0.08 ounce per cubic foot of air space. Propagation was not obtained with the special shelf arrangement

when the distribution was equivalent to 0.032 ounce per cubic foot or with the standard arrangement when the distribution was 0.040 ounce per cubic foot.

EFFECTS OF MOISTURE AND OF WET SURFACES.

During the summer of 1913 many tests were made with the mine surfaces wet (see p. 97). Comparison of the velocities and pressures recorded from these explosions with those obtained in tests made during the winter indicated that the presence of visible moisture had a marked retarding effect on the development of explosions. Even when the mine surfaces were wet, however, explosions were obtained with dry dust placed on the cross shelves, such dust being considered equivalent to the dust often found on cross timbers in mines. Evidently it is important that all the coal dust in an entry section be wet. Merely wetting the floor is not enough if there is dry dust on the ribs or timbers. No system of watering the dust is satisfactory unless it frequently washes down all the surfaces of the entry or working place being treated and thus makes accumulations of fine dry coal dust impossible, the wetted dust being shoveled up as it collects.

EFFECTS OF VELOCITY AND DIRECTION OF VENTILATING CURRENT AND OF STOPPING THE CURRENT.

In order to procure definite information on the effect of the velocity and direction of the air current on an explosion, several special tests were made (see p. 104). In one test the loading was symmetrically arranged in two entries, the igniting shot being placed in the stub entry off the last cut-through. A high-velocity ventilating current (850 lineal feet per minute) was used. The theory has been widely held among mining men that coal-dust explosions always travel against the air rather than with it. This explosion traveled with nearly equal velocity in either direction; that is, against the air and with it, being slightly faster in the direction of previous movement of the air current, but the difference would not permit the drawing of inferences therefrom. As a matter of fact, the air vanes have shown that at the start of an explosion the opposing air currents are immediately reversed. The sudden arrest of a long column of moving air may result sometimes in the bursting of light stoppings before the arrival of the explosion wave. All testing at the experimental mine supports the view that coal-dust explosions propagate in any direction in a mine, inward or outward, where there is dry coal dust of sufficient purity along its path.

Two other tests, one with pure coal dust and one with mixed dust, were made with symmetrical loading and no ventilating current. A violent explosion resulted from the coal dust loading and a strong explosion from the mixed-dust loading, exceptionally high pressures being recorded in the latter explosion. These tests showed, contrary

to the beliefs of many mining men in the western and southern coal fields, that stopping the ventilating current has no effect in preventing the start of an explosion.

DETERMINATION OF PREVENTIVE MIXTURES FOR PITTSBURGH COAL DUST.

In previous reports⁷ on coal dust the Bureau of Mines has pointed out that besides the method of wetting coal dust to prevent it from forming a dust cloud there is another way of neutralizing its potential danger—that first suggested by William E. Garforth—namely, to dilute it with an inert dust, such as shale dust. It was of course important to investigate the value of this method and to determine by tests how much inert material would have to be added so that an explosion could not be started, or, if started, could not propagate through the mixture. Accordingly a very complete series of explosibility tests was made with Pittsburgh coal dust and three kinds of incombustible material, the latter being two shales of different composition and a limestone dust. The limiting percentage that would not permit an explosion being initiated and the percentage that would not sustain an explosion that had started under more favorable dust conditions at some other point or by ignition of a body of fire damp were determined. The results of the extensive experiments are given later in this bulletin (see p. 141), but it may be stated here that the method gives great promise as a preventive of coal-dust explosions.

COOKED DUST.

In all of the tests careful observations of the coked dust deposits were made. After violent explosions coked dust was rarely found except near the origin, where the velocities were low. The deposits varied from isolated globules to layers of coke one-half inch or more thick, sticking to ribs and timbers. In explosions originating at the face of the main entry the coke deposits in that entry were almost entirely on the outby exposures of rib projections or of timbers; in other words, on the reverse side of such projections, whereas in the air course they were chiefly on the inby exposures on the side facing the movement of the explosion. This seeming inconsistency of deposition has not been satisfactorily explained, as apparently the conditions are identical. Frequently deposits were found on the exposures opposite to those on which the first deposits were sticking; these in some instances may have been due to the retonation or reverse waves. Small light globules which had evidently cooled

⁷ Rice, G. S., *The explosibility of coal dust*, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz: Bull. 20, 1911, p. 84; Rice, G. S., *Coal-dust explosions*: Miners' Circular 3, 1912, p. 8; Rice, G. S., *Notes on the prevention of gas and dust explosions in coal mines*: Tech. Paper 56, 1914, p. 10; Rice, G. S., and Jones, L. M., *Methods of preventing and limiting explosions in coal mines*: Tech. Paper 84, 1915, p. 14.

while being carried along were frequently found in considerable amounts on the floor in recesses.

The general conclusion is that where along its path an explosion increases in intensity, combustion of coal dust is more complete, the violence of the blast carrying along the dust, which burns until consumed. When the explosion is slower moving or where there is a great excess of coal dust, the molten coke is projected on to surfaces, both facing and reversed, but the subsequent blast of spent gases may scour off the coke particles on the facing surfaces. Movements of afterdamp gases immediately following an explosion with many branching paths in an extensive mine are erratic, and no generalizations can be made.

AUTOMATIC SAMPLING OF FLAME AND PRODUCTS OF COMBUSTION.

The automatic sampling devices developed in the course of the testing and controlled with precise timing for opening and closing gave instructive information regarding the composition of the mine atmosphere during and after the passage of the flame (see p. 52). It was found that the air remained of normal composition until the flame came very close to the point of taking the sample. At the moment the flame arrived gases distilled from the coal and the gases of combustion began to appear. At the same time the oxygen content of the air began to fall and the carbon-dioxide content started to rise rapidly. This process continued with the passage of the flame. In tests giving strong explosions practically all the oxygen was consumed. After the flame passed, distillation products of the coal—methane, hydrogen, ethylene, and possibly some carbon monoxide—were found, in addition to products of combustion—carbon dioxide, carbon monoxide, and coke; the water of combustion could not be identified. The total percentage of distillation gases varied from 1 per cent to as much as 12 per cent of the sample, the usual content being 1 to 6 per cent. The carbon dioxide varied up to 12 per cent. The carbon monoxide has three possible sources—insufficient oxygen, distillation from coal, and reduction of water by hot carbon; it varied from less than 1 to 11.6 per cent. The amount of methane distilled from the coal was in one test more than 4 per cent, and 2 to 3 per cent of methane was very common.

Comparison of air samples taken at the rib with those near the center of the entry showed that a layer of unburned air remained close to the rib, possibly screened off from the burning central part by a dense curtain of dust. This hypothesis is supported by numerous absences of the photographic registering of the flame in the manometers, especially when dust was loaded on a side shelf immediately in by the manometer. The gases near the rib analyzed in some instances 10 to 18 per cent of oxygen at the same moment that

those near the center had less than 1 per cent. These samples also indicated that the products of distillation are rapidly diffused and reabsorbed as the gases cool, especially carbon monoxide.

EFFECT OF SIZE OF DUST ON EXPLOSIBILITY.

An extensive series of tests was made to determine the effect of the fineness of coal dust on its explosibility (see p. 94). It was found that particles coarser than 20 mesh—the interval between the woven wires of a 20-mesh screen is about one thirty-second of an inch—had little effect in influencing the development of an explosion of Pittsburgh coal dust. The pressures developed and the velocity of the explosion increased as the percentage of fine sizes (percentages of 200-mesh dust were usually taken in making comparisons) increased; moreover, the percentage of shale dust necessary to prevent propagation increased with the percentage of fine sizes. An increase from 50 per cent to 80 per cent of shale dust was necessary to prevent propagation in Pittsburgh coal dust when the percentage of 200-mesh dust was increased from 10 per cent to 80 per cent of the coal dust through a 20-mesh screen.

These tests indicate the importance of the fine dust in propagating an explosion. As the rib dust, roof dust, and dust on timbers is usually very fine, any method of caring for the explosion hazard due to coal dust should include rendering inert this fine dust on timbers, roof, and ribs. In many watering systems such dust is entirely ignored.

EFFECT OF SUPERDUSTING NEAR THE ORIGIN OF THE EXPLOSION.

In single-entry loading, the open cut-through 50 feet from the cannon permitting release of pressure, difficulty had been experienced in obtaining duplicate results. An attempt was made to provide a uniform starting impulse by distributing a large quantity of coal dust near the origin of the explosion (see p. 95). The dust was arranged on temporary shelves in such a manner that practically all of it would be thrown into the air by the blast of the cannon. In three tests of this arrangement no explosion resulted. Two tests were made later to confirm this result. An explosion resulted in one, but not in the other. It was evident that the large excess quantity of dust thrown into the air by the concussion of the shot blanketed the flame from the cannon through absorption of heat and prevented the starting of explosive combustion. This result was confirmed by testing stations abroad when it was reported to them. It was found, however, that the same quantity of coal dust when placed on side shelves and the floor would not prevent the starting of an explosion, and subsequent testing with excess loadings of mixed dust showed no appreciable retarding of the propagation of an explosion once started.

INFLUENCE OF QUANTITY OF DUST.

In connection with the series to determine the influence of sizes of coal dust, the possible effect of the quantity present upon explosibility limits was investigated. It was found that after reaching the unit quantity of dust mixture—per linear foot of entry of each size of coal dust—that gave the approximate maximum explosive limit in the standard propagation test length of 300 feet, to increase the loading did not change the explosibility limit of that mixture. The loading giving the maximum limit is about one pound or more of coal dust in the mixture.

At first thought this result seems contrary to theory, because it would seem likely that the greater the quantity of dust the greater would be the cooling effect, and consequently the smaller the percentage of shale dust necessary to prevent propagation. This statement would be true if all the dust present were blown up in a cloud, but in mixtures of dust that are feebly explosive only a small proportion of the total quantity of mixed dust is blown up in a cloud. The physical effect, therefore, of the quantity of dust present in excess of a certain figure is nearly negligible on account of the fact that this excess dust does not get into suspension in the air.

In theoretical discussion, all the loading mentioned above—one pound of coal dust per linear foot of entry—being brought into suspension and evenly distributed through the air, there would be about 0.3 ounce per cubic foot (300 grams per cubic meter) of air space. With standard Pittsburgh coal dust, if there is complete combustion of the dust and complete exhaustion of the oxygen of the air at normal pressure by such combustion, it would require only 0.123^{7a} ounce of dust per cubic foot (see Bull. 20, Bureau of Mines, p. 50). Actually, however, there could never be absolutely uniform distribution of the dust, and with coarse dust, there would rarely be complete combustion, hence there must be an excess of coal dust in order to utilize all the oxygen in a unit of space. Moreover, as there is precompression of the air in advance of the flame of an explosion—which in one test, at 350 feet from the origin, apparently reached 127 pounds per square inch, or nearly 9 atmospheres, above normal—it would require 1.23 ounces of Pittsburgh dust per cubic foot (or 1,230 grams per cubic meter) to exhaust completely the oxygen per unit of air space at 10 atmospheres pressure.

EFFECT OF METHANE IN THE AIR CURRENT.

After the limiting mixtures to prevent either ignition or propagation of explosions had been determined, a series of tests was made to ascertain whether the presence of small percentages of gas in the air current would necessitate a higher percentage of rock dust in mixtures of coal dust and rock dust to give adequate protection

^{7a} A recalculation on a slightly different basis gave a value of 0.118 ounce. (See p. 587, Appendix).

(see p. 154). The use of more rock dust proved necessary. Roughly, for each per cent of gas in the air current 5 to 7 per cent more of incombustible material had to be added to the mixture to insure prevention of ignition or propagation.

EXPLOSIBILITY TESTS OF DIFFERENT COALS.

As laboratory tests and experience in the field indicated that dusts from different coal beds differed greatly in explosibility, the testing of other coals in addition to the Pittsburgh coal was thought desirable, in order to determine what measure of protection would be necessary in mines working such coals to insure against widespread explosions. Consequently at various times during the experimental period explosibility tests were made on the following coals; their explosibility was found to vary from the highest to the lowest in the order given (see p. 218).

Coals tested arranged in order of explosibility of dusts.

Coal bed.	Kind of coal.	State or Province.	Ratio V V+FC.
No. 5 seam, Indiana.....	Bituminous.....	Indiana.....	50
Vancouver Island.....	do.....	British Columbia.....	47
No. 4 bed, Red Lodge district.....	do.....	Montana.....	45
No. 6 bed.....	do.....	Illinois.....	42
Hastings bed.....	do.....	Colorado.....	42
Owl Creek bed.....	Subbituminous.....	Wyoming.....	42
Pittsburgh bed.....	Bituminous.....	Pennsylvania.....	40
Keokuk bed.....	do.....	Eastern Kentucky.....	38
Upper Freeport bed.....	do.....	Indiana County, Pa.....	32
Sewall bed.....	do.....	West Virginia.....	27
Coking coal bed, Crow's Nest.....	do.....	British Columbia.....	27
Lower Kittanning bed.....	do.....	Pennsylvania.....	25
Fire Creek bed.....	Semibituminous.....	West Virginia.....	22
Upper Freeport bed.....	do.....	Cambria County, Pa.....	21
Beckley bed.....	do.....	West Virginia.....	20
Lower Kittanning bed.....	do.....	Pennsylvania.....	17
Anthracite ^a	Anthracite.....	Lykens Valley, Pa.....	10
Anthracite ^b	do.....	Bernice, Pa.....	10
Do. ^b	do.....	Wyoming Valley, Pa.....	8

^a Low order of explosibility.

^b Not explosive.

The series included tests without any gas and with various percentages of gas in the air current. The results were plotted with the total incombustible content of the coal or mixtures of coal and shale tested as ordinates and the ratio of the volatile matter to the combustible matter, as abscissas. A surprisingly regular relation was found to exist between the explosibility of the dust and the ratio of volatile combustible to total combustible of the coal, the explosibility increasing as this ratio increased (see fig. 45, p. 396). Further tests of dusts from many other coals, particularly those from districts that have been immune from explosion disasters, are planned in order to determine whether the same relation exists for all coals. It is suspected that the structure of the coal when crushed to dust by the ordinary processes of mining may be a factor of sufficient importance

to cause some variation in the relations noted which deal with pulverized or finely ground dust. Relative explosibility as above discussed is determined by the limiting mixtures with inert dust that will propagate an explosion, and does not have reference to violence from explosions of the respective pure coal dusts.

TESTS WITH ORIGIN NEAR MOUTH OF MINE.

A series of tests (see p. 347) in which the cannon was placed in the entry at a point near the mine mouth was made to determine how far inby the mine mouth a shot must be placed in order that an explosion may travel into the mine. It was found that with pulverized Pittsburgh dust, the cannon being placed 100 feet inby the mine mouth, an explosion would not propagate inward, although large volumes of flame were projected from the mine mouth. The charge in the cannon was four pounds of powder and the direction in which the cannon pointed was immaterial at this point.

When the cannon was placed 168 feet within the mine mouth and charged with 4 pounds of powder, the explosion would propagate into the mine, the direction in which the cannon was pointed again being immaterial. When the cannon remained at 168 feet inby the mine mouth and the charge was reduced to 1 pound of powder, the explosion traveled into the mine when the cannon pointed inward, but did not travel into the mine when it was pointed outward. It was thus seen that the direction in which the cannon is pointed does have some effect, but this influence is not equal to that of a larger charge of powder.

The purpose of these tests was to determine whether an explosion could be started by a brushing shot near the mouth of a dusty bituminous mine or where a premade dust cloud, such as is caused by a moving trip being derailed, is formed in the presence of a source of ignition—an open light or electric flashes from a trolley or mining machine. Two of the worst mine explosion disasters in the United States were believed to have had such origin. In one of these a long trip of cars drawn by a trolley locomotive and running at a speed of 30 or 40 miles an hour broke in two; the rear half jumped the track about 600 feet or so from the mouth of the mine, knocking out timbers and throwing down the trolley wire. At this moment an explosion occurred, traversing the entire mine, which is very extensive, and killing almost instantly the motorman at the head of the first part of the trip, close to the mouth of the mine. Evidence indicated that the explosion had originated near the mine mouth and traveled several miles inward with more or less violence, becoming very violent at certain points near the face of the mine.

In the other disaster a trip of cars broke away and ran down a short incline, at the foot of which there was trolley haulage into the

mine. At this instant an explosion occurred; flames burst from the mouth of the mine, and the explosion traversed large areas of workings inside, including those of an adjacent connected mine. One of the causes suspected was that the runaway trip on wrecking itself at the foot of the incline raised a cloud of dust, which was ignited by a "short" of the trolley wire.

Judging from the tests described in the following pages, the initiation of an explosion near the mouth of a mine depends upon the extent and density of the dust cloud. A large enough cloud, of sufficient density, will burn when ignited with such quickness that it develops pressures enough, in spite of the relief afforded by the near-by mine opening, to continue the raising of an advance dust cloud and thus to permit the propagation of what may be termed the preliminary inflammation.

The difference between inflammation and what may be considered explosive combustion can not be precisely defined. It appears to depend upon the quantity of dust in the air in relation to the size of the passageway. Pressure is evidently necessary to continue propagation, because the pressure of gases confined by walls, roof, and floor develops longitudinal movement that must be of high enough velocity to bring up dust in a sufficiently dense cloud for ignition and self-propagation from point to point. Moreover, unless there are confining walls this mechanical agitation of dust will not result and the flame will quickly die away, as the dust particles will not be sustained in the air by eddying currents of high velocity. Experiments in smooth pipe-like surface galleries in England have shown that violent coal-dust explosions are not likely to occur unless obstructions like timbering are placed in the gallery, thus indicating that eddying air currents are requisite to mix and sustain dust prior to propagation.

ROCK-DUST ZONES.

A number of tests were made to ascertain the efficiency of zones of incombustible rock dust ^a of given lengths in stopping explosions started in zones of pure coal dust (see p. 413). In practically all tests the rock-dust zone successfully stopped the explosion after some penetration of the flame. Nevertheless, as the rock-dust zones in mines would become more or less contaminated with coal dust it is believed that reliance should not be placed on rock-dust zones at various points in a mine for stopping explosions when there are intermediate zones not rock-dusted, but rather that the entire length of entry where coal dust accumulates should be rock-dusted.

In order to determine how much coal dust could be deposited on a rock-dust zone before it failed to check an explosion, a series of tests

^a The term rock dust is used herein as a generic term instead of stone dust, shale dust, etc., because in a geologic sense the term rock may designate the large masses in a bed or deposit that may be mined to make the dust; moreover, rock dust is a more inclusive term than shale dust or limestone dust.

was made to determine the limiting proportions when the coal dust was scattered on top of the rock dust as compared to the limits previously determined when the two dusts were intimately mixed. The limits were nearly the same, the former arrangement requiring a little more rock dust than when the two materials were mixed. This result is important, for in a commercial mine using the rock-dusting method of preventing explosions coal dust is likely to become scattered over the rock bed before rock dust is again distributed.

EFFICIENCY OF VARIOUS SIZES OF ROCK DUST FOR PREVENTING EXPLOSIONS.

Pulverized shale dust of which 90 to 95 per cent, and occasionally more, passes through a 200-mesh screen, was used in nearly all of the tests to determine the relative explosibility of coal dusts from different seams. However, as the rock-dust method gained favor it seemed desirable, in consideration of the higher cost of fine grinding, to use a coarser dust if the loss of efficiency were not too great. Consequently a series of tests was made with coarse shale, 95 per cent of which passed through a 20-mesh screen, and 27 to 30 per cent through a 200-mesh screen. In only one of these tests did the percentage of coarse shale fail to prevent propagation through a mixture that would not support an explosion when pulverized shale dust was used. The results might be summarized in the statement that the increased proportion of shale dust necessary when the content of 200-mesh dust is reduced from 90 or 95 to 30 per cent was only 5 to 10 per cent, providing all the shale would pass through a 20-mesh screen. If it is desirable that a rock dust having a somewhat smaller percentage of fine dust be used, an increased quantity of rock dust should be distributed, so that the quantity of fine dust present shall be the same or more than that shown by the explosibility limit. For example, suppose that the coal dust in question has a propagation limit of 50 per cent admixed shale dust; that is, a ratio of one to one. If it is desired to use a rock dust of which only 60 per cent passes through a 20-mesh screen, it will be necessary to use enough so that this 60 per cent will equal the amount of coal dust, and the ratio of total rock dust to coal dust will then be 10 to 6, or 1.67 parts of rock dust to one part of coal dust.

SPECIFICATIONS OF DUST FOR EFFECTIVE ROCK DUSTING.

The rock dust should fulfill the following requirements:

The content of combustible matter should be very small, in order that as large a percentage as possible of the material will be effective for offsetting the effect of the combustible coal dust, and to avoid adding combustible matter.

The dust should not have sharp edges or points. This requirement is desirable because it is believed that the diseases resulting from

breathing the rock dust produced by drilling in some metal mines are primarily caused by the hard, sharp edges of the dust injuring the lungs. Shale dusts, pure limestone dusts, and similar materials are practically free from such sharp edges or are soluble. Bituminous dust has not been found unhealthful. Dusts containing much free silica or flinty particles should not be used for dusting.

Theoretically the finer the rock dust is, the greater would be the proportion that could be blown easily into a dust cloud and the greater would be the area of cooling surfaces exposed; but practically a dust somewhat coarser than 100 or 200 mesh is believed to be better. A large part of the finely pulverized dust seems to stick to the walls on which it is thrown, almost like a paint, whereas coarser dust does not tend to pack or stick in the same degree, and so it is more easily blown off. Dust of about 20-mesh size with 20 to 30 per cent of fine dust is believed to be a satisfactory material for dusting.

The material should have no marked tendency to absorb or collect moisture. Dust that is at all deliquescent, although it might be useful in preventing the formation of clouds of coal dust and thus addition of fuel to the explosion flame, would also fail to make rock dust clouds and would not be very effective in quenching an explosion already under way.

A suitable dust for rock dusting should therefore have very little combustible content and no sharp-edged or pointed particles, should be a mixture of fine and coarse grains, and should not be deliquescent.

In the testing in France and in Great Britain, as well as at the experimental mine at Bruceton, Pa., shale dust has been tried chiefly on account of the ease of getting shale in coal mines and on account of its favorable showing as a neutralizing agent of coal dust, also because of its general freedom from free silica.

On account of shale being used in the early trials such terms as "shale dusting" and "shale-dust barriers" have been extensively used in current technical publications; the Bureau of Mines, however, thought it wise to use a more generic term, such as "rock dust," to include all dusts of a noncarbonaceous character that might be used for the purpose.

Wherever the roof strata contain a shale of suitable character, free from coaly matter and not sandy, they are the most convenient source of material from which to make protective dust. Often the roof shale from falls or brushing is loaded out and dumped on the waste pile, and in any event can easily be sent to a crusher and pulverizer on the surface. The shale should not contain more than 5, or at the most 10, per cent of combustible matter. Not all roof or floor shale in coal mines can meet the above requirements. Often the roof shale is interlaminated with coal and is too sandy or too

clayey. Under such circumstances suitable material must be sought in surface croppings or be transported from a quarry.

Tests at the experimental mine have indicated the value of pure limestone dust. The density of limestone is somewhat greater than that of shale, but not different enough to be of importance in making an extinguishing dust cloud. In some parts of the country limestone dust is a waste product where limestone is quarried for building. If the quarry is not too distant such dust often can be obtained at a lower cost than dust could be produced in a local pulverizing plant.

It is thought that limestone dust presents some advantages from the production of carbon dioxide when being "burned" by the flame. This reaction would absorb heat and the gas would assist in extinguishing the flame. At least one of the gas samples taken when limestone dust was used in a test indicated an excess of carbon dioxide over that from the combination of the coal dust and oxygen; perhaps this excess came from the "reduction" of the limestone dust. It is not thought, however, that this result can be depended upon as an important factor because of the time element, and any preference for limestone dust over shale must be on other grounds, chiefly the cost. One practical feature, however, favors the use of limestone—namely, the whitening of the passageways where the dust is used and the resulting improvement of the illumination with miners' lamps.

The British authorities experimented in their gallery with flue dust and various other kinds of dust. However, as flue dust and many other dusts they tried were not found to be safe for use, because of the effect when breathed and because a sufficient quantity would be difficult to obtain cheaply, it was not considered necessary to test them at the experimental mine.

PLACING ROCK DUST IN MINES.

For the same reason that coal dust placed on cross shelving proved to be in the most effective position for obtaining propagation of explosions, undoubtedly the most effective placing of rock dust to prevent or check explosions is on cross shelves spaced at uniform intervals of 6 to 10 feet over the roadways throughout the mine. In the majority of coal mines, however, this arrangement is not practical on account of insufficient head room. In such mines recourse must be had to placing the rock dust on side shelves along the rib or on cross timbers, but chiefly by throwing rock dust on the ribs and by filling recesses with it after the coal dust has been cleaned up. Enough rock dust will probably fall in this process to make the roadbed safe. An initial application of 4 or 5 pounds per linear foot will render a clean entry safe from coal-dust explosions for several months, perhaps for six months, if the mine coal and the coal dust are prevented from spilling freely off cars. Subsequent applications will

not take as much rock dust as the first, but from time to time samples of the mine dust should be collected and analyzed in order to insure that the average combustible content does not rise above the explosive limit for the dust of the particular coal in question.

ROCK DUST BARRIERS.

Throughout the test period rock-dust devices for limiting explosions were tested. Six devices for different mine locations were invented⁹ by one of the investigators (G. S. Rice) and five of these were given very complete tests. Some were more uniformly successful than others, but it is believed that if properly installed in mines all will effectually stop or limit any explosion that may have originated in unprotected workings. These devices have been described in detail in Technical Paper 84;¹⁰ the results are summarized in this bulletin (p. 486).

EXPLOSIONS ORIGINATING IN WIDE PLACES.

There has been much conjecture as to whether coal-dust explosions could be produced as easily in rooms or wide places as in narrow workings or entries. It is true that many explosion disasters are believed to have originated in a room, even where fire damp had not been reported previously or was found after the explosion. Under these conditions of initiation, however, several large blasts had usually been fired at the same time. It was questioned, therefore, whether a single blast of moderate size—less than 4 pounds, say, of black powder—would make sufficient disturbance to blow up a cloud of dust which would be ignited by the shot and in turn give sufficient pressure to continue an explosion. Such experiments were, of course, beyond the compass of gallery tests; hence no light had been thrown on this matter by experiments abroad or by previous experiments in the United States.

After the series of tests to determine the explosibility limits of different coal dusts had reached such a stage that tentative conclusions could be formed a number of tests were undertaken relative to the starting of explosions in a wide place. The results of these tests indicated that a coal-dust explosion could be originated in a room of ordinary dimensions by a blown-out shot containing 4 pounds of black powder stemmed with clay, and that such an explosion could spread through crosscuts to adjoining rooms on either side, as well as to the entry from which the group of rooms was turned.

Experiments were then made to determine the efficiency of rock dusting on an entry when an explosion was started in a group of four rooms coated with pure coal dust. It was thought that the

⁹ Patents applied for assignment to the Bureau of Mines for free use of public.

¹⁰ Rice, G. S., and Jones, L. M., *Methods of preventing and limiting explosions in coal mines*: Tech. Paper 84, Bureau of Mines, 1915, pp. 21-42.

explosive combustion of coal dust in such a group of rooms would be continued so long that while the first darts of flame into the entry might be extinguished, a continued flaming might permit the explosion ultimately to travel through the rock-dusted entry. Such travel did not occur, however, in several more or less severe trials. Further testing must be done to establish definitely this point, for although rock dusting of rooms is practicable, it may not always be done efficiently.

TESTS TO DETERMINE COMPARATIVE EFFECT OF WEAK AND STRONG STOPPINGS ON AN EXPLOSION.

The question as to the comparative effect of weak and strong stoppings near the origin of an explosion has been raised frequently. It has been argued that if the stoppings near the origin were weak and blew out immediately the pressure of the explosion would be relieved and the flame would die out. On the other hand, the failure of these stoppings might throw dust into the air of the parallel entry or room from accumulations that are apt to collect in cut-throughs, thus extending the explosion in new paths.

Some support is given the previous theory that an explosion dies away with the bursting of stoppings by several failures to start explosions from the face of the main entry when dust was loaded only in that entry and none in the last cut-through. This cut-through was without a stopping, as is always the case in ordinary mining, for circulation of air. No failures in starting an explosion occurred, however, when dust was also placed in the cut-through. If sufficient coal dust was found at the head of an entry to propagate an explosion under ordinary mining conditions, it is inevitable that the crosscut would be no freer from dust than the entry.

WEAK STOPPINGS OF NO ADVANTAGE.

In the tests at the experimental mine there were many instances in which the blowing out of a stopping after an explosion was well started did not affect the continuance of the explosion, and there were no instances where it did affect continuance. Hundreds of instances of no checking of an explosion have been found after mine disasters, although practically every stopping in the mine had been blown down. The relief afforded by weak stoppings therefore is of doubtful value, and their use has certain disadvantages. Such stoppings are usually leaky, and if a disaster does occur, every stopping has to be renewed before the mine ventilation can be restored. The experimental mine has undergone several hundred tests, many of the explosions being more violent than those indicated in disasters that have cost the lives of many men, yet only one of the reinforced concrete stoppings has yielded, whereas a brick stopping formerly

used in one crosscut and wood stoppings in the butt entries have been thrown down in a number of tests.

Several tests were made in the butt entries in order to obtain some information on explosions there (see p. 369). At the time of making these tests the butt entries were 350 feet long, measured from the air course. Cut-throughs had been driven, connecting them every 100 feet, the last being 50 feet from the face. The first cut-through from the air course had a heavy reinforced-concrete stopping of the same type as that in the cut-throughs between the entry and the air course. The second and third cut-throughs between the butts were open.

Explosions were originated at the face of No. 2 butt in one series and at the face of No. 1 butt in another series of tests. In some of the tests there were no stoppings in the second and third cut-throughs. In other tests heavy plank stoppings were installed there, being braced in place in such manner that the explosion would not destroy them.

For the first test light board stoppings plastered to make them air-tight were built in each of the open cut-throughs and so arranged that the pressure of the explosion destroyed them immediately. The results did not differ appreciably from those obtained with explosions in which there were no stoppings at all in the cut-throughs. Consequently, in order to conserve time and material comparative tests were made with no stoppings and with strong stoppings that would withstand the pressures of the explosions.

With a given mixture of pulverized Pittsburgh coal dust and pulverized shale dust the flame extended somewhat farther when the stoppings were in place than when they were not in place, although the increase in explosibility in this test was counteracted by 5 per cent additional shale dust in the mixture. The results were similar in both No. 1 and No. 2 butts.

A greater difference, however, was obtained with coarser coal dust, 95 per cent of which would pass through a 20-mesh screen and 10 per cent of which would pass through a 200-mesh screen. In order to counteract the increase of explosibility caused by closing the cut-throughs, more than 10 per cent additional shale dust was required in the mixture, which would raise the explosibility limits to practically the same figure as that found in standard double-entry testing in the main entries.

However, the difference is slight and the result is of academic rather than practical interest, because erecting strong stoppings in both cut-throughs converted either entry into a long single gallery such as would not be found in commercial mines where the legal requirements of ventilation would compel the last cut-through to be opened.

The results of this series of tests were not conclusive and further testing will have to be done. Nevertheless, the results indicate that as regards preventing an explosion from starting, the difference between using strong stoppings, weak stoppings, or none at all near a source of ignition is so small as to be negligible in practical mining operations. That relief of pressure through side openings does not of itself prevent an explosion from propagating was frequently illustrated in this series of tests by the fact that explosions were started more readily in the No. 1 butt entry, off which rooms are turned, than in the No. 2 butt entry, which has no room openings.

One thing was very noticeable in these tests in the butt entries, namely, that explosions, while starting and propagating, were less violent than those in the main entries; that is, the pressures and velocities are low. The reason for this difference is not altogether clear, but it is thought to be due to the butt entries being turned squarely off from the air course. Because of this arrangement, shock waves may be reflected which collide and interfere with the advance air waves and retard the movement of the air column that stirs up the dust in advance of the flame, making propagation of an explosion possible. The effect was particularly noticeable in the second butt entry, the mouth of which faces the rib wall of the air course. The first butt entry is opposite a cut-through in which there is a strong reinforced-concrete stopping 20 feet from the side of the air course, giving opportunity for the air cushioning of an impinging blast coming out of the first butt entry.

These suggestions refer only to the initial development of pressure and velocity; they do not raise any doubt regarding the probability of an explosion from either butt entry being propagated in both directions along the air course, provided that dust conditions and other factors are favorable, as such extension has frequently taken place.

CHAPTER II.—DESCRIPTION OF EXPERIMENTAL MINE AND EQUIPMENT.

THE SITE.

The experimental mine, in which the tests described in this bulletin were made, is near Bruceton, Pa., on the Baltimore & Ohio Railroad, 13 miles southwest of the central part of Pittsburgh, Pa. The site was selected after careful search for the most favorable natural conditions for explosion testing. Mine drifts were started in December, 1910, in the side of a ravine that opens into a valley through which the railroad runs. The mine opening is one-fourth of a mile from the railroad and is 100 feet higher than the roadway. A view of the mine site and the grounds at the station appear in Plate I (frontispiece).

SURFACE PLANT.

The surface plant of the experimental mine, except for some additions, has been discussed in detail in Bulletin 56.¹¹ A brief description of the plant follows.

The power house contains one 60-horsepower and one 80-horsepower boiler, with feed pumps and a feed-water heater, and a small engine generator set used primarily to supply power for the instruments and air compressor.

The plant for making coal dust includes a hammer crusher and a pulverizer driven by a steam engine; dust-collecting bins, elevators, and storage bins are housed in a separate building.

The mine-ventilating appliances comprise a high-speed, 8-foot centrifugal fan equipped with doors and housing for quick reversal of the air current and with explosion relief doors. Connecting the fan to the mine is a steel fan-drift, which also has intermediate explosion relief doors. The fan is driven by a steam engine. In addition a small auxiliary fan, with a gas-engine drive, has been installed at another opening for emergency use.

A gas-engine hoist at the head of an incline lowers coal cars to the tippie at the railroad and hauls up supplies.

The instrument control and recording observatory consists of a bomb-proof room connected with the office rooms and a dark room for developing photographic records.

¹¹ Rice, G. S., and others, First series of coal-dust explosion tests in the experimental mine: Bull. 56. Bureau of Mines, 1913, pp. 26-31.

Equipment incidental to the operation of the mine includes a barn, small blacksmith shop, storage and tool house, oil house, pump house, water reservoir in the ravine, elevated water tank, drilled well, and magazine for explosives.

A gas main passes through the property from which natural gas, composed of 88 per cent methane and 12 per cent ethane, is obtained for making gas-explosion tests, for gas and coal-dust tests, and for operating the gas engines.

Temporary wooden explosion galleries have been built from time to time in the development of an inexpensive means of making field demonstrations of the explosibility of coal dust. Moreover, explosion barriers have been erected on the surface for the study of their mechanical arrangement and for demonstration purposes, in addition to underground installations for checking explosions.

UNDERGROUND WORKINGS AND EQUIPMENT.

A detailed description of the coal bed, the mine entries, and the underground instrument stations and arrangements as they were at the end of the first series of tests, February, 1912, is given in Bulletin 56.¹²

The coal bed, its mining conditions at the site of the experimental mine, and the arrangement of the mine workings at the beginning of the second series of tests (test 16 was made September 12, 1912) were as follows: The Pittsburgh bed in this locality has a thickness of from 5 feet to 5 feet 6 inches of nearly clean coal. This is overlain with "draw slate," or friable clay, 1 to 2 feet thick, which must be taken down immediately after mining the coal because of its rapid decrease of strength on exposure to the air. Above that is the "roof coal," comprising 1 to 2 feet of alternate layers of coal and shale. This coal makes an excellent roof, generally requiring no timbering in entries, and it has withstood the shocks of the explosions in most places, though occasionally slabs become loose and must be pulled down. The cover over most of the workings ranges from 75 to 132 feet. The mine is practically self-draining and is, with the exception of one or two sections, quite dry during the cold months, when most of the testing is done. No appreciable amounts of methane have ever been found in the mine, although samples of mine air are regularly gathered and analyzed.

The entries at the beginning of this period were two parallel drift entries 1,270 feet long, termed the "main entry" and the "air course," although used interchangeably for haulage and ventilation; they were subsequently driven to about 1,300 feet. A single butt entry 100 feet long is driven to the right from the main entry at a

¹² Rice, G. S., and others, First series of coal-dust explosion tests in the experimental mine: Bull. 56, Bureau of Mines, 1913, pp. 17-26, 32-33.

point 775 feet from the opening, and a pair of butt entries 200 and 250 feet to the left from the air course, at points 850 and 900 feet from the main opening (see fig. 1, p. 14). A slant connection intersects the air course from the left at a point 117 feet from its opening. This slant connects the mine to the outside steel fan drift. There is a 41-foot pillar between the entries, which are 9 feet wide and average $6\frac{1}{2}$ feet high. Cut-throughs were made between the main entries at 200-foot intervals and between the butt entries at 100-foot intervals. All cut-throughs are closed with reinforced-concrete stoppings 18 inches thick, except the second one in the left butt, which is bratticed or has a test stopping placed in it as may be desired, and the last ones for each pair.

The concrete stoppings have successfully withstood the pressure of the explosions except the one which was situated in 650 cut-through. This stopping, which had a small doorway in it (see Pl. II, A) was at a point where many of the explosions reached their maximum pressure. It was cracked by successive explosions and was finally blown open, hinging like a door and taking the position shown in Plate II, B. Its former position can be identified by the rods still projecting from the roof and ribs. It was replaced by a reinforced concrete stopping 2 feet thick.

Two rooms were turned and driven in December, 1913, from No. 1 left butt at points 85 and 129 feet from the air course. The necks were made only 7 feet wide. Twenty-one feet in from the entry the rooms were widened toward the left to a width of 20 feet. The pillar between the rooms is 24 feet thick.

The main openings of the mine are concrete portals heavily reinforced to be strong enough to withstand the force of the most violent explosions. A detailed description of the construction and method of reinforcing is given in Bulletin 56.¹³ The main entry for a distance of about 180 feet into the opening has been lined with reinforced concrete. All of these reinforced linings inside of the portals have been more or less broken by the earlier violent explosions of pure coal dust, in which barriers were not used.

Two types of instrument stations, large ones and small ones, have been constructed at various points in the mine. These stations have been fully described in Bulletin 56.¹⁴

The large stations have two chambers and are constructed of concrete. One chamber is for the instruments, which are connected to the entry through holes in a fixed thick steel plate separating them from the entry. The other chamber provides an entrance to the rear of the instruments for adjusting them. The entrance way is closed by a steel door flush with the side of the entry. These stations are

¹³ Rice, G. S., and others, work cited, pp. 19-24.

¹⁴ Rice, G. S., and others, work cited, pp. 33-37.

used for instruments which record pressure, flame velocity, and direction of movement of the gases.

The small stations contain only flame-velocity instruments. The larger stations are 200 feet apart and the small ones are intermediate, so that records of flame velocity are obtained at 100-foot intervals. For convenience in recording observations the main entry and air course are designated as E and A, respectively; the No. 1 and No. 2 left butts are designated by 1B and 2B, respectively. For points in the main entry or the air course the letters are followed by numbers giving in feet the distance from the drift mouth, and for points in the butt entries the distance from the air course.

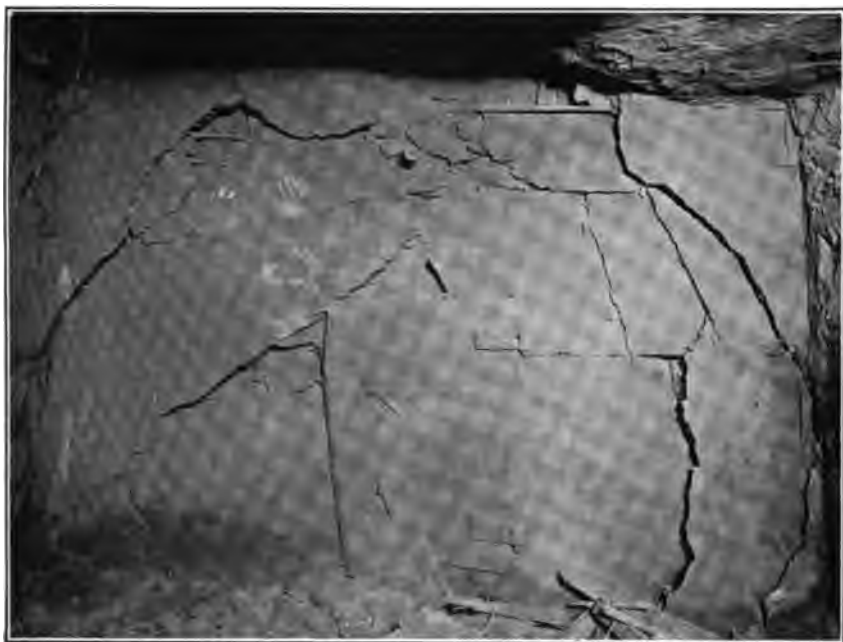
In addition to the two large instrument stations at E 50¹⁵ and E 150 used during the first series of tests, stations of a similar type were constructed prior to this testing period in the coal rib at E 350, E 550, E 750, E 950, and E 1150 and small stations at E 250, E 450, E 650, E 850, E, 1050, A 1050, and A 900. During the early part of 1914 additional large stations were built at A 1150, A 950, A 750, and A 550.

More changes were made during the summer of 1914. The butt entries were extended to total lengths of 300 and 350 feet, and two additional rooms were turned from No. 1 left butt, with the necessary cut-throughs between the rooms. Four large instrument stations were constructed at 1B 50, 1B 250, 2B 50, and 2B 250, and cables were laid in pipes in the rib to connect these to the stations previously built. The arrangement of the cables and instrument stations in different parts of the mine is shown in figure 1 (p. 14).

Considerable difficulty had been experienced at times in cleaning the fine coal dust from the floor, ribs, and roof of the entries after explosions; also there was some speculation as to whether dust abraded from the coal ribs and roof, together with dust more or less combustible derived from the road ballast, might not affect the results of the tests. For these reasons it was decided to lay a concrete floor and to coat the sides and roof of the main entries for the inner 350 feet of each entry, and the cut-throughs, in this part of the mine, with a cement-sand lining. This coating was put on the coal ribs and roof by means of a "cement gun" in the fall of 1914, no reinforcing being used in this work (see Pl. III, A). Also, as the shale roof weathers rapidly when exposed to air currents, especially the intake air of variable temperature and humidity, it was thought that coating the roof would protect it from such action, thus preventing possible roof falls and reducing the expense of timbering.¹⁶ The results at the experimental mine have been favorable.

¹⁵ The expressions E or A with a number following means that the point referred to is in the entry or air course at a distance, in feet, from the main opening equal to the number given.

¹⁶ For a discussion of this problem see Rice, G. S., Weatherproofing mine roof and walls and making tight stoppings with a cement gun; Proc. Coal Mining Inst. of America, 1917, p. 78.



A. STOPPING AT E 650 PARTLY DESTROYED BY EXPLOSION.



B. STOPPING AT E 650 COMPLETELY DESTROYED BY EXPLOSION.



A. GUNITE APPLIED TO SURFACES OF CUT-THROUGH AND STOPPING.



B. CANNON PREPARED FOR FIRING, SHOWING IGNITION WIRE.

WIRING SYSTEM.

ELECTRIC POWER.

The power for operating the instruments is furnished by a 110-volt direct-current generator, which gives a flat or essentially perfect regulation at the laboratory for instrument purposes. All instruments are adjusted carefully for the same voltage, and throwing one instrument on or off does not affect the others. The portable storage batteries first used for the instruments, as described in Bulletin 56, were found to be of inadequate capacity when the work developed and more apparatus was put into use; therefore they were discarded and the power is now taken directly from the generator. As the instruments are all designed to be used on low voltage, an adjustable resistance unit of 600 ohms maximum resistance was placed permanently in the circuit of each instrument wire in the large cable. In this way the current for any instrument can be easily controlled.

CABLES.

The wiring from the laboratory into the mine comprises two cables, one containing three wires for lights and motors and the other 31 wires for the instruments. The power wires are in a separate cable, in order to avoid any possible induction from the heavier currents to the circuits of the delicate instruments. The larger cable consists of 30 No. 16 wires and one No. 10 wire, which is used as a common return for all circuits except that for shot firing. Of the 30 No. 16 wires in the cable two are used for shot firing, one for the telephone, and one to record the moment of ignition of the explosion; the other 26 are all available for the record of any phenomenon desired.

From the laboratory the cables extend aboveground to a point near the mouth of the main entry (see fig. 1, p. 14). Passing through a safety cut-out box, they are carried into the mine through a pipe embedded in the rib and faced with concrete. In the large instrument stations, which are situated every 200 feet along the entry, the large cable is attached to back-connected terminal boards having binding posts on the front (see Pl. IV). All splices and connections are made in junction boxes which are filled with an insulating compound to prevent corrosion.

SAFETY CUT-OUTS.

In the laboratory the two shot-firing wires go through a switch box so arranged that the box can not be shut unless the plugs that close both sides of the circuit are out and the circuits open. At the point where the cables go underground all wires pass through a second switch box which can be locked with every wire opened.

Before explosive is taken into the mine for loading the shot that initiates the explosion all the switches are opened and both boxes are locked, the keys being carried into the mine with the explosive. The boxes are not unlocked again until every man is out of the mine and everything is ready for the test. The key for the box in the laboratory is not delivered until all the switches at the mine mouth are closed and everyone is in a safe position. These precautions prevent the possibility of premature firing by induced or leakage currents or by accidental closing of the shot-firing circuit, which has occurred in certain mines using electric shot firing from the surface where similar precautions have not been used.

INSTRUMENTS USED IN TESTS.

The principal instruments used in these tests comprise three general classes—those for measuring the times at which the various phenomena of the explosion take place, those for measuring the pressures developed at different stations, and those for taking samples of gas during and immediately after the explosion.

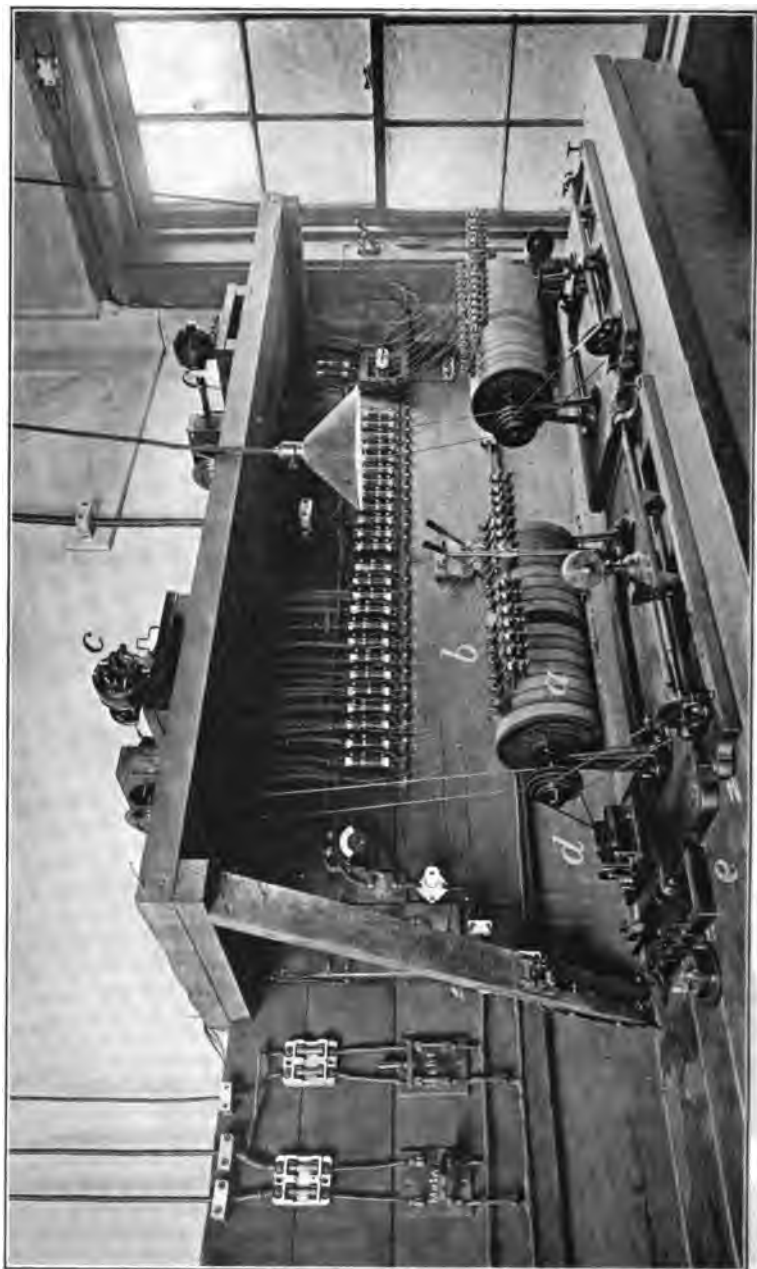
The time-measuring instruments are two chronographs like those used by J. Taffanel at the French testing gallery at Liévin, France. The distinguishing feature of this type is that each circuit has its own separate recording pen. These chronographs are described in more detail on page 39.

The instruments for recording the pressures developed consist of three manometers as designed for the use of the British Coal Dust Commission at Altofts, which are described in Bulletin 56; three photographic manometers as designed for the use of the French testing gallery at Liévin and five improved photographic manometers, designed by the bureau's investigators, using the same general principles as the French manometers. In addition to these recording manometers two types of instruments have been tried for measuring the maximum pressures, as described on page 49.

Four types of gas samplers were tried in this second series of tests, the B. C. D. type (described in Bulletin 56) having been discarded as unsatisfactory for the conditions at the experimental mine. The four types tried were developed in the Bureau of Mines instrument shop as the work progressed. One of these, the B. M. automatic sampler, model A, has been used regularly for more than two years. The B. M. sampler, model B, was abandoned after a few trials because of its slow closing. Another type consisted of simply an evacuated steel bottle that was opened as the explosion came by; it had an automatic device for sealing, but no further means of control. This type was used only a short time, as its results could not be correlated with the development of the explosion.



INTERIOR OF LARGE INSTRUMENT STATION: *a*, TERMINAL BOARD FOR 31-WIRE CABLE; *b*, TERMINAL OF 3-WIRE CABLE; *c*, FRENCH MANOMETER; *d*, AIR-DIRECTION INDICATOR; *e*, TIN-FOIL BLOCK; *f*, CABLES.



CHRONOGRAPHS INSTALLED IN THE OBSERVATORY: a, DRUM WITH RECORD ON IT; b, PENS; c, DRIVING MECHANISM;
d, TIMING DEVICE FOR MODEL C SAMPLER; e, TUNING FORK.

The Bureau of Mines sampler, model C, was developed during the fiscal year ended June 30, 1917. It proved so satisfactory that four more instruments were ordered, but they were not completed in time to be used for tests described in this bulletin. The special feature of the model C sampler instrument is that it can take a sample of gas from the center of the entry, whereas the other types had to be placed in the rib. Any number of samples can be taken at predetermined intervals of time. This sampler is described in detail on page 52 of this bulletin.

TIME-MEASURING INSTRUMENTS.

CHRONOGRAPH.

The time measurements are now recorded on two chronographs (see Pl. V) manufactured by Carpentier of Paris, similar to those used by Taffanel at Liévin. Each chronograph has a large drum 8 inches in diameter and 20 inches long, which is rotated at a peripheral speed of about 20 inches per second. The record paper, which has a metallic surface, is placed on this drum and given a heavy coating of camphor smoke. The records are made by means of small magnetically operated pens resting lightly on the paper; there are 15 such pens on each chronograph. The starting or stopping of the current through the magnet of a pen causes the tip to move at right angles to the motion of the paper a distance of 1 millimeter. These tips are made of celluloid and have very little friction with the metallic surface, thus requiring only a weak current to operate them. As the drum rotates the pens are moved along by means of a lead screw, tracing a helix on the drum. Either chronograph can be run for 15 seconds before any pen moves into the record of the next pen.

Each pen is connected to a certain wire going into the mine, and the opening or closing of any circuit operates the corresponding pen. With the system previously used all the circuits had to be broken successively in order to be recorded by the same pen. The present method permits the recording of many happenings, such as the operation of barriers and the movements of obstructions or of air vanes, regardless of their order of occurrence. For instance, in measuring the time of operation of a barrier a fine copper wire, No. 27 Brown & Sharpe gage, is so placed that it will be broken at the critical point in the operation of the barrier. A wire this size is too small to affect the operation of the barrier. This wire is in the circuit of one of the chronograph pens and the instant of its breaking is recorded by the pen. Anything so arranged that it will either close or open an electrical circuit can be recorded thus on the chronograph.

One pen on each drum is connected in series with a tuning fork which breaks and remakes the circuit 100 times per second. A series of marks are made 0.01 second apart, by means of which the time of the break in a circuit as recorded by any pen on that drum can be measured. Another pen on each drum is in series with a very fine wire (No. 36 gage), called the "ignition wire," which is stretched across the muzzle of the cannon (see Pl. III, *B*, p. 37). The time of the breaking of this wire by the igniting shot is taken as the zero for all time measurements for a given test and is called the "time of ignition."

After a test is over the chronograph pens are all let down on the paper so that the ignition pen rests on the record of that line. By making a short transverse movement of all pens a mark is made on the tuning-fork record which corresponds to the time of ignition, and which is therefore the zero point for counting time. Similarly, the record of any other pen the time of whose operation it is desired to measure is transferred to the tuning-fork curve, and the time from the ignition to this point can be directly counted in one-hundredth second intervals. After marking all the points desired the record is fixed so that it will not rub off by dipping in a bath of brown shellac varnish. When the varnish has dried, the paper is removed from the drum for study.

TIN-FOIL INDICATORS.

The method of obtaining the flame velocity is to place tin-foil strips at 100-foot intervals along the mine and record on the chronograph the fusing of these strips (see *a*, Pl. VI, *A*). The tin foil, which is 0.0004 inch thick and 0.125 inch wide, is placed over two brass posts three-fourths of an inch apart and is held in place by a gum band passing around the posts. These posts project one-fourth inch from the bottom of a vertical groove, one-half inch wide and one-half inch deep, in the end of a 2-inch wooden block. The circuit breakers are fastened in the instrument-station plates situated midway between the roof and the floor. The electric circuit connection inside the station is shown at *e* in Plate IV. The use of tin foil and its arrangement in wood blocks proved more satisfactory than any other devices tried.

Occasionally the foils are torn out ahead of the flame by the violence of the so-called "pioneering air wave" carrying dust. This form of circuit breaker, however, generally permits obtaining comparative time records of the fusing of the foils at the different stations. This record is a small fraction of a second behind the actual flame as photographed by the manometers. As hereafter described, it has been found both in these tests and in those by Taffanel at the French gallery that the flame of a coal-dust explosion projects wedge shaped

in advance of the general flame. This explains the apparent lag, because that part of the flame which is first photographed may be only the projecting wedge in the middle of the entry, and the extension to the sides of the entry not take place until a moment later.

That the flame is pointed was further demonstrated by placing a set of six foils at various points in the cross section of the entry at

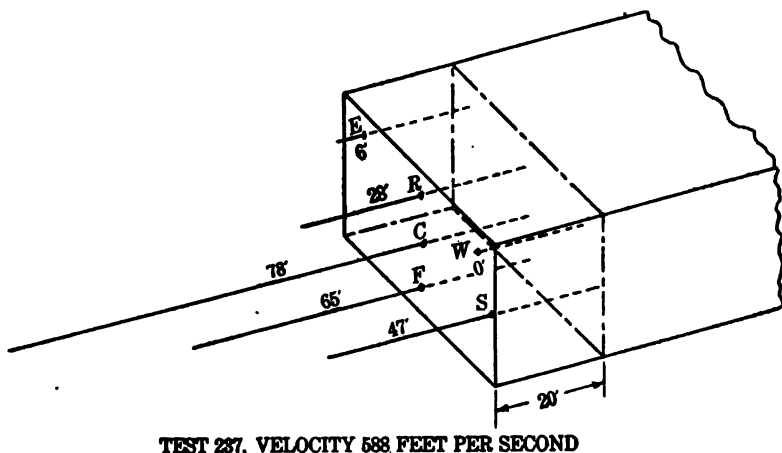
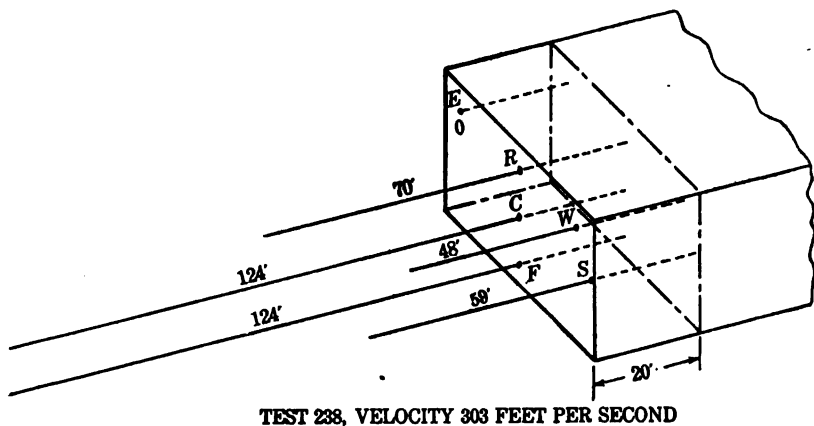


FIGURE 2.—Diagrams showing that explosion flame has a pointed or wedge-like front. Relative length of lines show comparative distances flame has traveled in different parts of cross-section by the time that last tin foil has fused.

E 1150. These foils were situated as follows (see fig. 2): Three were placed across the top of the entry 1 foot from the roof, one of these being 1 foot from the east rib, another 1 foot from the west rib, and the third midway between the ribs. A fourth foil was placed in the center of the entry, on a vertical post, and another foil, 1 foot from the floor on the same post. The sixth foil was the regular station

foil, being on the side at a point midway between the roof and the floor.

The records showed that the foil in the center of the entry always went out first, followed by one near the floor at a time interval that was generally very small. If the explosion traveled with high velocity, the station foil halfway up on the rib fused third, followed by the three near the roof in varying order. The time of fusing station foil varied from 0.03 to 0.21 second behind the foil near the floor, the time of fusing of the remaining foils varying from 0.1 to 0.04 second after that of the rib foil. In slow explosions the station foil fused about the same time as the roof foils—sometimes before, sometimes after. The records of these foils for six of the tests are given in Table 1.

TABLE 1.—Time of fusing of tin-foils situated at station E 1150, tests 226 to 241.

Test No. ^a	Foil situated at—					
	Center.	Floor.	Station.	Roof.	East side.	West side.
	<i>Seconds.</i>	<i>Seconds.</i>	<i>Seconds.</i>	<i>Seconds.</i>	<i>Seconds.</i>	<i>Seconds.</i>
227 ^b	0.608	0.630	0.660	0.693	0.729	0.740
235 ^c	.843	.847	.943	1.189	1.319	1.042
238 ^c	1.537	1.537	1.752	1.714	1.946	1.794
236 ^d	1.148	1.477	1.646	1.538	1.497	1.549
239 ^c	2.253	2.653	3.177	2.474	2.482	2.639
241 ^d	2.947	3.021	4.171	2.971	2.972	.....

^a Foils were not fused in tests not listed above. The time values given in this table were measured from the moment of firing the cannon shot.

^b Fast, violent explosion.

^c Slow explosion.

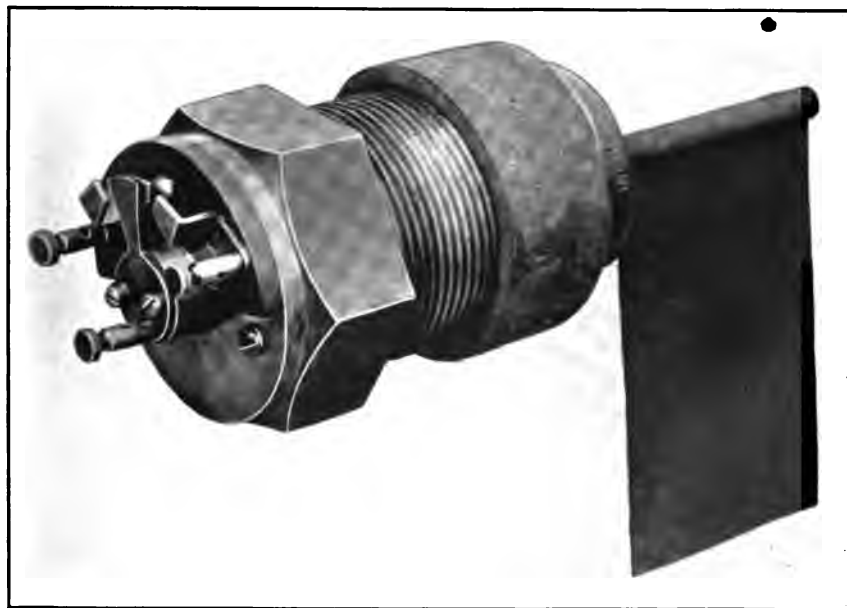
^d Slow explosion did not propagate throughout.

Figure 2 represents diagrammatically the records of the foils for tests 237 and 238. The upper part of the figure, which is for test 238, shows two planes representing cross sections of the entry at E 1150 at different instants during the passing of the flame. The front plane, shown in solid lines, represents the instant of fusing of foil E, which was situated 1 foot from the roof and near the east side of the entry or left-hand side of the section. This foil was the last one of the set at E 1150 to go in this test. The projections to the left indicate by their respective lengths the relative times of the fusing of the various foils, or the equivalent distances each respective part of the flame was ahead of that section represented by the front plane. Test 238 shown here was a slow velocity explosion.

The lower diagram represents similarly the conditions for test 237, in which the explosion had a higher velocity. The projecting lines represent the advance of the various parts of the flame ahead of that section which fused the last foil—the one situated near the roof on the west side of the entry (at W). The results establish the fact that an explosion proceeds with a long central tongue in advance, the combustion then spreading vertically and horizontally toward the walls.



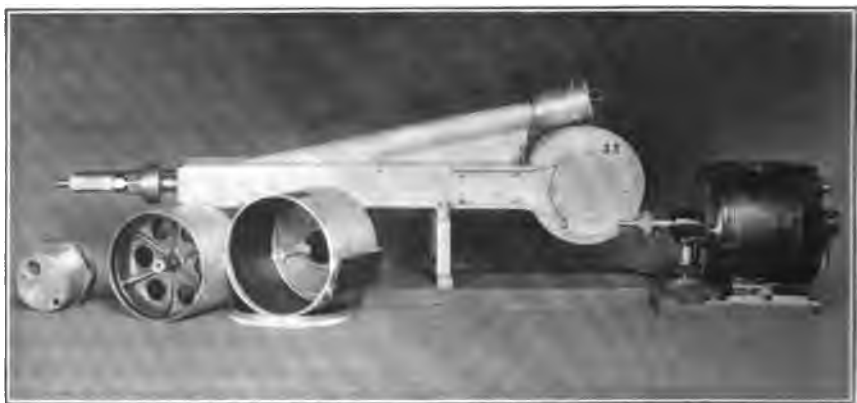
A. LARGE INSTRUMENT STATION: *a*, TIN-FOIL BLOCK WITH TIN FOIL IN PLACE; *b*, AIR-DIRECTION INDICATOR; *c*, MANOMETER PLUG, FRENCH, OR BUREAU OF MINES TYPE.



B. AIR-DIRECTION INDICATOR.



A. DEVICE FOR MEASURING VELOCITY OF AIR MOVEMENTS.



B. MANOMETER FOR MEASURING THE PRESSURES DEVELOPED BY AN EXPLOSION.

Another factor that probably causes a delay in the fusing of the station foils, or may even prevent their fusing, is the cooling effect of the ribs. This results in the explosion temperature near the walls being much lower than that near the center of the cross section of the entry. The temperature curve is analogous to the curve of decreasing temperatures of burning flue gases measured at different points in the cross section of a boiler tube. Actual measurements¹⁷ have shown that the temperature of the gases in a 3-inch boiler tube may be 1,075° C. at the center, 1,000° C. at a point one-half inch from the wall, and 200° C. at the wall.

DETONATOR INDICATORS.

Experiments were also made with mercury fulminate detonators for indicators to obtain records of the passage of the flame, the high temperature causing the detonator to explode and break a wire in the chronograph circuit. These results were found not to be reliable, probably because the moisture in the mine air affected the priming, and also because the copper shell may have trapped the coal dust preceding the flame, thus shielding the fulminate from the effects of the high temperature.

AIR-DIRECTION INDICATORS.

After many experiments with various trial devices an instrument has been developed and built by the bureau for indicating the direction of movement of the air or gases preceding, during, and after an explosion. This instrument is shown in Plate VI, *B* (p. 42). A small vane 3 by 5 inches in size hangs from a horizontal shaft, and is kept in a downward position by means of a coil spring, in addition to the action of gravity. The instrument is so designed that in the event of a violent explosion, in which the vane may be damaged or torn away, the holding mechanism is not damaged and the vane can be easily replaced. The strength of the spring is such that movement of air in either direction at a velocity of 50 or more feet per second will swing the vane. When the vane has turned through an angle of 30°, a switch is closed, which operates a pen on the chronograph. A movement backward toward the original position opens this switch, releasing the pen, and if continued in the opposite direction closes another switch, which in turn operates a second pen. In this way the time of any air movement through the entry can be recorded in its proper relation to the other features of the explosion. Three of these instruments have been used at various locations in the mine. An instrument is shown in position in the mine at *b*, Plate VI *A*. The connections inside the station are shown at *d*, Plate IV (p. 38).

¹⁷ Kreisinger, H., and Barkley, J. F., Measuring the temperature of gases in boiler settings: Bull. 145, Bureau of Mines, 1918, p. 30.

VELOCITY RECORDING DEVICE FOR AIR AND EXPLOSION GASES.

As mentioned in Bulletin 56,¹⁸ Berthelot found that flame passes through a uniform gaseous mixture at a permanent velocity, which he termed "l'onde explosive." Prof. H. B. Dixon has called this the "explosion wave," and he states that "the explosion wave travels with the velocity of sound in a burning gas which itself is moving forward en masse in the same direction." In an analogous manner the "explosion wave" in a mixture of coal dust and air travels through that mixture, although it is not known experimentally whether the wave attains a permanent maximum velocity. Practically it could not, owing to the improbability of obtaining a dust and air mixture of uniform density. However, the explosive combustion advances through the dust and air mixture in a manner similar to that in a gaseous mixture; also there is at the same time a longitudinal mechanical movement of the column of air and dust. Generally this movement takes the same direction as that of the explosion wave, but sometimes through the contraction of the cooling gases after the explosion has passed it may be opposed to the direction of the explosion wave. Under the latter condition the explosion flame may be stationary or even pass backward, with reference to the walls of the passageway, but generally such conditions are only momentary, like pulsations. When there is such brief stationary position of the flame, the effect on the walls and objects exposed to the flame is very noticeable.

The velocity records of flame and pressure movement obtained by the station indicators show the net velocity resulting from the explosion wave and the movement of the air and gas. It was thought that valuable information might be obtained by getting some registration of the mechanical movement of the air and gas mixture. Accordingly a number of devices were tried.

EARLIER DEVICES TRIED.

Several attempts have been made to measure the velocity of the air and gases as distinct from that of the explosion. A movable vane held by a spring was attached to a mirror in one of the photographic manometers. This device was calibrated to measure the pressure of the moving gases impinging on the vane, and from this pressure the velocity of the gases could be calculated. It was found on trial that the delicate and complicated nature of such an instrument made it unserviceable, as it was damaged or wrecked by explosions.

¹⁸ Rice, G. S., and others, First series of coal-dust explosion tests in the experimental mine, 1913, p. 2.

THE SLIDING VANE OR TROLLEY.

The device in use at the present time (see Pl. VII, A) is the outgrowth of a number of things tried. A vane or rider is placed to slide on a heavy wire about 125 feet long stretched near the roof of the entry. The rider is an aluminum tube one-fourth inch in diameter by 4 inches long, carrying a sheet-rubber disk 4 inches in diameter held by two smaller aluminum disks. Twenty-five feet from the inby end of the wire a switch is so placed that it will be opened by the passing of the rider. A second switch is placed at the outby end of the wire. The opening of these switches is recorded on the chronograph in the laboratory, thus the time and velocity of the disk's motion obtained. One of these devices is placed with the switches at E 650 and E 550, and a shorter one 75 feet between switches, from E 1025 to E 950.

TABULATION OF RESULTS OBTAINED WITH "TROLLEY."

The records from these devices have been somewhat inconsistent because of the exceedingly rapid changes of conditions that take place during an explosion, but they are given in Table 2. However, a better idea of their value can be obtained from the test curves shown on pages 74 to 88.

Six positions of the trolley are embraced in these tests. The first three, with exceptions, were beyond the point to which the flame extended at the time the disk had completed its run. In the last three positions the trolley was generally within the flame zone.

TABLE 2.—Results obtained from gas velocity recording device known as the trolley.

1. POSITION, STATIONS E 550 TO E 450.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switch operated at—		Indicated flame velocity during trolley movement.	Pressure (pounds per square inch) at E 750 at time trolley switches operated at—	
		E 550.	E 450.		E 550.	E 450.		E 550.	E 450.
	1914.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>		
108	Apr. 27	2.594	2.891	324	E 1093	E 1074	63	0	0
110	May 2	2.111	3.898	54	E 1072	E 894	101		
111B	May 5	1.296	1.712	226	E 1194	E 1160	82	2	1
112	May 8	1.110	2.398	74	E 1227	E 1184	149	(a) 0	(a) 0
113	May 9	1.018	1.245	420	E 734	(b)	.....	6	9
115	May 20	1.028	c 1.080	c 1,836	(b)	(b)	.....	31	31
116	May 25	1.635	c 1.685	c 1,908	(b)	(b)	.....	25	25
117	May 27	2.167	2.929	125	E 1097	(b)	.....	0	2
120	June 11	5.758	6.245	205	E 855	E 789	136	5	0
126	June 22	1.052	1.857	124	E 1258	(b)	.....	0	17
129	June 25	2.309	5.296	32	E 1196	(b)	.....	0	0
132	June 27	1.915	2.822	105	E 1170	(b)	.....	0	1
136	July 7	2.916	3.512	160	E 1014	E 856	265	3	1
138	July 10	1.010	1.766	132	(b)	(b)	.....		
139	July 15	1.110	1.821	140	(b)	(b)	.....	15	0
143	Oct. 30	1.132	3.885	36	E 1207	E 877	120		
145	Nov. 9	1.090	1.340	394	E 992	(b)	.....	6	6

* Pressure at E 550.

† Flame extinguished before switch operated.

‡ Probably shock wave of strong explosion opened switch before trolley reached it.

46 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 2.—Results obtained from gas velocity recording device known as the trolley—Continued.

2. POSITION, STATIONS E 650 TO E 550.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switches operated at—		Indicated flame velocity during trolley movement.	Pressure (pounds per square inch) at E 750 at time trolley switches operated at—	
		E 650.	E 550.		E 650.	E 550.		E 650.	E 550.
	1914.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>		
154	Dec. 28	0.795	3.800	33	E 1287	E 1224	21	2	0
155	Dec. 31	.797	3.708	34	E 1254	E 1204	17	2	0
	1915.								
156	Jan. 5	.808	3.718	33	E 1240	E 1046	67	2	0
159	Jan. 15	.750	2.804	49	E 1210	E 1076	65	2	0
161	Jan. 21	.890	1.021	764	E 844	E 544	2,290	2	50
164	Jan. 26	.859	3.051	44	E 1292	(b)	.....	0	3
171	Feb. 5	.829	5.053	24	E 1292	E 980	74	0	2
174	Feb. 9	.917	2.816	53	E 1188	E 1010	94	2	0
175	Feb. 12	1.887	2.605	139	E 1095	(b)	.....	1	2
182	Feb. 20	.908	1.667	132	E 1156	E 964	385	2	4
184	Mar. 3	1.116	2.668	64	E 1245	E 1214	20	2	1
188	Mar. 12	.923	1.601	147	E 1169	(b)	.....	2	3
189	Mar. 16	1.139	1.388	503	E 914	(b)	.....	7	11
190	Mar. 18	.981	1.313	301	E 1058	(b)	.....	4	6
194	Mar. 24	1.554	1.918	275	E 1114	(b)	.....	1	3
195	Mar. 29	2.180	3.145	104	E 1204	(b)	.....	0	4
197	Apr. 6	1.000	2.098	91	E 1174	E 1011	148	2	0
201	Apr. 13	1.206	1.663	230	E 1122	(b)	.....	0	6
202	Apr. 17	1.458	2.201	135	E 1201	E 880	432	0	6
204	Apr. 21	2.16	3.28	79	E 1245	E 891	316	0	15
206	Apr. 24	.973	1.323	286	E 1133	E 994	397	2	2
207	Apr. 27	1.020	2.318	77	E 1197	E 1026	132	1	1
209	May 3	2.257	1.200	51	E 1247	E 1050	101	0	1
211	May 6	2.189	2.776	170	E 1153	(b)	.....	0	3
213	May 7	3.537	4.808	79	E 1140	(b)	.....	0	2
214	May 10	1.017	3.175	46	E 1224	(b)	.....	2	0
215	May 11	1.006	1.863	116	E 1154	E 970	215	1	1
218	May 12	1.311	1.787	210	E 1248	E 1150	206	0	2
221	May 19	1.024	3.194	46	(b)	(b)	.....	1	0
223	May 20	2.128	2.528	250	E 1126	E 955	425	1	3

3. POSITION, STATIONS A 650 TO A 550.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switches operated at—		Indicated flame velocity during trolley movement.	Pressure (pounds per square inch) at A 750 at time trolley switches operated at—	
		A 650.	A 550.		A 650.	A 550.		A 650.	A 550.
	1915.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>		
171	Feb. 5	4.437	5.710	79	A 1006	A 834	135	0	0
174	Feb. 9	1.445	3.253	55	A 1156	(b)	.....	0	0
175	Feb. 12	2.218	3.240	98	(b)	(b)	.....	4	0
178	Feb. 17	1.866	2.755	112	(b)	(b)	.....	4	0
182	Feb. 20	1.238	2.499	69	A 1022	(b)	.....	2	0
184	Mar. 3	1.753	3.308	64	A 1250	A 1044	132	1	0
188	Mar. 12	1.155	2.212	95	A 1054	(b)	.....	2	0
189	Mar. 16	1.255	1.320	1,538	(b)	(b)	.....	7	6
190	Mar. 18	1.198	2.068	115	(b)	(b)	.....	4	0
194	Mar. 24	1.832	1.907	1,333	(b)	(b)	.....	10	3
195	Mar. 29	2.679	3.762	92	A 974	(b)	.....	0	0

b Flame extinguished before switch operated.

TABLE 2.—Results obtained from gas velocity recording device known as the trolley—Continued.

4. POSITION, STATIONS E 1027 TO E 952.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switches operated at—		Indicated flame velocity during trolley movement.	Pressure d (pounds per square inch) at time inby trolley switch operated at—		Pressure d (pounds per square inch) at time outby trolley switch operated at—	
		E 1027.	E 952.		E 1027.	E 952.		E 1150.	E 950.	E 1150.	E 950.
	1915.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>				
197	Apr. 6	0.469	1.493	73	E 1252	E 1090	158				
201	Apr. 13	.649	1.314	113	E 1284	E 1060	337	1		14	3
202	Apr. 17	1.080	1.938	87	E 1256	E 1041	251	1	1	6	8
204	Apr. 21	2.134	3.042	83	E 1247	E 1066	199	1	1	6	9
206	Apr. 24	.470	.883	179	E 1245	E 1152	225	2	0	3	5
211	May 6	1.878	2.521	117	E 1194	E 1080	177	1	1	6	10
213	May 7	2.547	4.530	38	E 1204	E 1064	71	0	0	1	2
215	May 11	.580	1.503	81	E 1225	E 1093	143	1	2	4	4
223	May 20	2.033	2.236	369	E 1157	E 1090	330	4	6	10	11
246	Nov. 16	.461	.637	426	E 1237	E 1154	472	8	1	15	10
248	Nov. 22	.578	.780	371	E 1197	E 1106	451	7	3	11	5
249	Nov. 24	.524	1.250	103	E 1200	E 1057	197	5	4	2	0
251	Nov. 30	.499	1.070	131	E 1224	E 1041	315	4	3	8	6
262	Dec. 1	.433	1.503	70	E 1252	E 1085	147	4	1	2	0
254	Dec. 6	.551	1.566	74	E 1230	E 1086	142	2	2	2	0
255	Dec. 7	.479	2.334	40	E 1222	E 1106	63	2	1	0	0
256	Dec. 9	.597	1.593	75	E 1215	E 1083	122	4	3	1	0
267	Dec. 10	.549	1.145	126	E 1214	E 1053	270	5	2	6	2
258	Dec. 13	.662	1.805	66	E 1221	E 1080	123	3	2	2	0
259	Dec. 15	.589	2.303	44	E 1229	E 1104	73	2	2	0	1
260	Dec. 17	.558	1.074	145	E 1227	E 1007	427	4	3	9	7
261	Dec. 20	.538	.977	171	E 1211	E 1118	212	4	3	8	7
262	Dec. 22	.501	.598	773	E 1139	E 1074	671	17	6	17	16
	1916.										
267	Jan. 5	.401	2.260	40	E 1244	E 1145	53	3	1	1	0
269	Jan. 10	.422	1.395	77	E 1247	E 1085	187	3	1	3	1
270	Jan. 12	.395	1.343	79	E 1248	E 1119	136	4	2	2	0
271	Jan. 14	.383	2.629	33	E 1241	E 1161	36	5	2	1	0
272	Jan. 17	.372	1.520	65	E 1260	E 1146	100	3	1	1	0
273	Jan. 19	.389	2.725	32	E 1257	E 1152	46	4	1	0	0
274	Jan. 21	.394	.928	140	E 1248	E 1104	170	4	3	8	7
282	Feb. 5	.390	1.280	84	E 1260	E 1104	175	4	2	4	4
283	Feb. 8	.457	3.891	22	E 1278	E 1118	47	1	0	0	0
285	Feb. 14	.374	1.141	98	E 1250	E 1109	184	4	3	3	4
286	Feb. 15	.472	3.508	25	E 1276	E 1108	55	0	0	2	2
287	Feb. 17	.400	.585	405	E 1266	E 1229	200	4	2	3	3
288	Feb. 19	.381	.776	190	E 1247	E 1167	203	4	2	4	4
290	Feb. 24	.396	1.098	107	E 1256	E 1025	329	6	2	6	4
292	Feb. 29	.462	1.341	85	E 1275	E 1116	181	1	1	10	11
296	Mar. 8	.392	1.365	77	E 1250	E 1112	142	4	2	2	2
298	Mar. 13	.379	1.693	57	E 1262	E 1094	128	2	2	2	2
299	Mar. 15	.388	1.147	99	E 1245	E 1104	186	3	3	3	4
300	Mar. 17	.390	1.391	75	E 1260	E 1115	145	3	2	2	2
302	Mar. 22	.418	1.015	126	E 1254	E 1048	345	4	1	7	7
304	Mar. 27	.408	2.565	35	E 1284	E 1076	97	1	1	5	5
306	Mar. 31	.398	1.861	51	E 1207	E 1114	105	3	2	1	1
308	Apr. 5	.423	2.550	35	E 1260	E 1161	47	3	1	0	0
314	Apr. 24	.430	2.427	38	E 1284	E 1014	135	1	1	9	9
317	Apr. 28	.400	2.687	33	E 1257	E 1154	45	2	2	0	0
318	May 1	.409	1.819	53	F 1244	E 1118	118	2	1	1	2
319	May 8	.472	1.782	57	E 1274	E 1026	189	1	1	9	11
320	May 6	.403	1.499	69	F 1242	E 1083	142	3	2	4	4
321	May 8	.387	.558	439	F 1234	E 1192	246	3	2	3	3
322	May 10	.382	1.229	89	E 1261	E 1111	177	3	2	3	3
323	May 11	.377	1.441	70	F 1261	F 1223	31	3	3	1	1
326	May 17	.410	1.812	53	F 1279	E 1133	104	3	2	1	1
329	May 25	.381	1.165	96	E 1230.	E 1115	147	4	3	2	3

^d In connection with the pressure records it should be remembered that the point of highest pressure is probably at the hottest part of the flame. For example, if the flame has passed E 1150 at the time of operation of a switch, there will possibly be at some point outby E 1150 and inby the trolley disk a pressure higher than that recorded at E 1150.

TABLE 2.—Results obtained from gas velocity recording device known as the trolley—Con.

5. POSITION, STATIONS E 1037 TO E 952.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switches operated at—		Indicated flame velocity during trolley movement.	Pressure δ (pounds per square inch) at time inby trolley switch operated at—		Pressure δ (pounds per square inch) at time outby trolley switch operated at—	
		E 1037.	E 952.		E 1037.	E 952.		E 1150.	E 950.	E 1150.	E 950.
	1916.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>				
339	Oct. 30	0.474	1.848	62	E 1248	E 1091	114	3	2	7	8
342	Nov. 6	.430	1.437	84	E 1246	E 1020	224	3	3	11	10
343	Nov. 8	.499	2.150	51	E 1233	E 1073	97	3	1	2	2
344	Nov. 10	.504	1.577	79	E 1273	E 1028	228	1	2	16	15
345	Nov. 13	.462	1.158	122	E 1231	E 1026	295	4	1	13	12
346	Nov. 15	.472	1.362	96	E 1274	(^b)	.....	2	1	27	14
347	Nov. 17	.578	0.780	409	E 1190	E 1044	702	9	3	29	62

6. POSITION, STATIONS E 1052 TO E 952.

Test No.	Date.	Time of opening of trolley switch.		Velocity of trolley.	Position of flame at time trolley switches operated at—		Indicated flame velocity during trolley movement.	Pressure δ (pounds per square inch) at time inby trolley switch operated at—		Pressure δ (pounds per square inch) at time outby trolley switch operated at—	
		E 1052.	E 952.		E 1052.	E 952.		E 1150.	E 950.	E 1150.	E 950.
	1916.	<i>Seconds.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>			<i>Ft. per sec.</i>				
354	Dec. 4	0.498	1.912	71	E 1237	E 1040	138	3	2	2	3
355	Dec. 6	.525	2.843	43	E 1280	E 1019	113	1	1	4	5
357	Dec. 11	.550	2.872	43	E 1290	E 1027	109	1	1	3	4
360	Dec. 18	.581	1.067	204	E 1191	E 1081	226	6	3	11	10
361	Dec. 20	.554	0.875	299	E 1230	E 1119	346	7	4	9	9
362	Dec. 22	.442	1.108	149	E 1201	E 1034	251	5	3	9	5
363	Dec. 27	.479	1.688	82	E 1231	E 1051	149	4	3	2	3
	1917.										
365	Jan. 3	.602	1.754	86	E 1267	E 1057	182	2	1	11	9
368	Jan. 9	.648	2.337	59	E 1264	E 1016	147	1	1	8	8
370	Jan. 12	.692	2.243	64	E 1290	E 1092	128	1	0	15	11
371	Jan. 16	.443	.761	311	E 1214	E 1131	261	4	2	11	9
372	Jan. 18	.458	2.611	46	E 1226	E 1055	80	3	1	0	1
373	Jan. 19	.470	1.499	96	E 1270	E 980	282	3	2	8	11
374	Jan. 22	.462	3.186	36	E 1246	E 1074	63	2	2	0	0
382	Feb. 26	.430	2.962	40	E 1238	E 1099	94	3	1	0	0
383	Feb. 27	.409	1.041	158	E 1221	E 950	429	7	1	15	11
384	Mar. 1	.420	1.550	88	E 1254	E 1014	212	3	2	7	5
385	Mar. 2	.388	1.170	128	E 1215	E 1041	223	6	2	8	9
386	Mar. 5	.548	2.265	58	E 1283	E 940	200	0	1	6	11
388	Mar. 7	.478	1.602	89	E 1281	E 974	273	2	1	8	10
389	Mar. 8	.429	1.423	101	E 1224	E 1064	161	4	1	6	7
391	Mar. 9	.969	1.351	207	E 1280	E 1054	469	0	1	20	24
394	Mar. 14	.418	2.296	53	E 1249	E 1114	72	3	2	1	1
395	Mar. 15	.356	1.187	119	E 1228	E 960	322	5	4	8	9
396	Mar. 20	.380	1.581	83	E 1229	E 1116	94	4	2	1	1
401	Mar. 26	.600	3.740	32	E 1279	E 1040	76	1	1	0	1
406	Apr. 3	.385	1.596	88	E 1227	E 1047	149	3	2	4	4
411	Apr. 10	.439	3.700	31	E 1252	E 1072	55	3	1	0	0
438	Dec. 26	.349	1.921	64	E 1237	E 1104	85	5	3	1	1
439	Dec. 28	.381	1.322	106	E 1234	E 1030	217	5	2	5	6
	1918.										
441	Jan. 8	.451	2.444	101	E 1274	E 960	158	1	1	7	9
444	Jan. 18	.365	2.212	54	E 1257	E 1077	97	4	3	0	0
446	Jan. 24	.396	2.002	62	E 1255	E 1070	115	4	3	3	2
450	Feb. 1	.498	2.069	45	E 1264	E 986	135	1	1	4	6
461	Feb. 4	.365	1.267	111	E 1237	E 1008	254	5	3	6	6
462	Feb. 6	.412	2.325	52	E 1255	E 1081	91	3	2	2	1
453	Feb. 8	.362	1.427	94	E 1248	E 1125	116	4	2	2	1
456	Feb. 16	.409	1.264	117	E 1241	E 991	264	4	1	7	3
458	Feb. 20	.370	2.584	45	E 1261	E 1038	66	5	2	2	0
470	Mar. 28	.498	3.447	34	E 1270	E 1042	77	1	1	1	1
471	Mar. 29	.444	2.777	43	E 1284	E 1064	107	1	1	5	7
472	Apr. 1	.389	1.582	67	E 1240	E 1084	118	4	2	2	2
474	Apr. 4	.406	1.923	66	E 1218	E 1084	102	3	2	2	2
486	May 7	.409	1.479	93	E 1259	E 958	281	4	1	6	6
487	May 10	.322	1.310	101	E 1257	E 958	303	4	3	7	8

^d In connection with the pressure records it should be remembered that the point of highest pressure is probably at the hottest part of the flame. For example, if the flame has passed E 1150 at the time of operation of a switch, there will possibly be at some point outby E 1150 and inby the trolley disk a pressure higher than that recorded at E 1150.

When tests with the trolley were being made it was thought that some relation could be established between air or gas velocity and flame velocity. One of the uncertainties was whether the friction of the device in running on the wire was a factor of importance; it was believed that the friction was small and in any case would be a constant. On the other hand, the violent eddying of the air in some tests may have thrown the trolley disk or its carrying wire against the roof. Undoubtedly it would have been better, had that been physically possible, to have had the path of the trolley along the axis of the passageway. On the whole, however, the trolley was successful in recording approximately the velocity of the air column in advance of the explosion, provided the flame did not approach the disk before the latter had completed its travel. When the flame passed the disk before the second switch was open, return waves would check the movement of the disk and render the record valueless. Also the mere approach of the flame to the disk marked the occurrence of disturbances that affected the record obtained. Although attempts to find a relation between the trolley velocity and other explosion records were but partly successful the apparatus was of value in designing the tripping devices for rock dust barriers. (See pp. 572, 583.)

PRESSURE-MEASURING INSTRUMENTS.

B. C. D. MANOMETERS.

The three B. C. D. manometers used during the early part of the second series are described on pages 56 and 57 of Bulletin 56, except for the method of measuring the speed of revolution of the drum. Only one of the Deprez indicators on each instrument is used, and this one is connected in the ignition circuit, as mentioned in the description of the chronograph on page 39 of this bulletin. The switch in this circuit is closed about one second before the shot-firing switch; the discharge from the cannon opens the circuit, as described on page 59. The end of this mark, which is made on all manometers of this type, indicates the instant of ignition; the duration, which is indicated on the chronograph, gives the speed of rotation of the manometer drums.

FRENCH TYPE OF MANOMETERS.

The French type of manometer (c, Pl. IV, p. 38) records the movement of a spot of light reflected from a movable mirror upon a photographic film on a revolving drum. The pressure of the explosion acts through a short $\frac{1}{4}$ -inch tube on a disk spring 1.6 inches in diameter, which is rigidly clamped around the edge. The motion of the center of the spring is transmitted through a small pin to one

side of the pivoted mirror. By adjusting the mirror so that it is tilted somewhat at the zero position of the spring, negative as well as positive pressures may be recorded. The sensibility of this type of spring decreases with the deflection. For this reason the manometer can be made very sensitive to small pressures, while being at the same time strong enough to withstand without damage the high pressures that are sometimes obtained. The importance of this type of manometer for the purpose of registering rapidly changing pressures, as compared with the B. C. D. and other manometers of steam-gage indicator types, is in the lightness of the moving parts—the plunger, mirror, and attachments are all of small dimensions—and the slight amplitude of movement, which makes the inertia of the moving parts inappreciable.

An entry view of the plug containing the pressure tube and flame photograph aperture is shown at *c*, Plate VI, A, page 42.

The light is obtained from a tungsten lamp of the auto-headlight type, which is operated considerably above normal efficiency in order to obtain the proper actinic qualities. The path of the light is from the lamp through a "pinhole" to the mirror. From here it goes to a reflecting prism, where it is turned upward at right angles and passing through a slot strikes the film. The films, 3.5 inches by 16 inches in size, are loaded on a drum in a small box, which may be carried from the dark room to the mine. When placed on the manometer a gear on the outside of the film box meshes with the gears of a constant-speed motor.

The time of revolution of these manometers is measured by means of two contact brushes mounted on the film box. These brushes are electrically connected to a pen on the chronograph, and rest against the brass gear that is on the outside of the film box, thus completing the circuit. A small insulating strip in the path of one of the brushes causes the chronograph pen to operate with each revolution of the drum, thus giving the time of one revolution of the film. By making the insulating strip a different width for each manometer the same circuit and pen can be used for all manometers.

Along one side of each manometer of this type a tube was constructed which has a glass-covered aperture into the mine passageway and a lens focussing on the revolving film. This device permits photographing the flame in its proper time relation to the pressure wave. The interference of a dust curtain along the rib and deposition of dust on the glass prior to the passage of the flame in many tests prevents obtaining a record of the flame.

The relation of these pressure records to the time of firing the originating shot is obtained by means of the record of the shock wave from the cannon, which is always shown clearly on the film. The time at which this shock wave passes a given station is measured

by suspending small vanes in the center of the entry in such a manner that they break an electrical contact on a slight movement of the air. These vanes are placed opposite the instrument stations and are connected to pens on the chronograph. As the time at which the shock wave from any firing point reaches a certain station remains fairly constant, frequent determination is not necessary. The general method adopted was suggested by Taffanel when on a visit to the experimental mine in May, 1914.

BUREAU OF MINES MANOMETER.

An improved manometer (Pl. VII, B, p. 43) was built in the instrument shop of the Pittsburgh station on the same general principles as the French manometers, but embodying several changes in construction. Nearly all the parts are cast aluminum. The arrangement is such that the light travels directly from its source to the mirror and thence to the film without any further change in direction. This manometer gives a much larger percentage of flame records than the French manometers, probably because the reflecting prism is eliminated. The interior parts of this instrument are easily accessible for cleaning, which is an essential feature for instruments at the mine. The film drum is driven by a worm and gear inclosed in a dust-proof case. A loose universal connection between the worm and motor permits easy adjustment or removal of the latter. The manometer and motor are clamped to a heavy cast-iron base to insure alignment and prevent vibration.

This type of manometer proved to be so successful that it was adopted as the standard for this work and is termed the Bureau of Mines manometer. It is possible that this manometer may be useful in other lines of work for the measurement of rapidly changing pressure.

MAXIMUM-PRESSURE GAGES.

COPPER CYLINDER TYPE.

The maximum-pressure gages described on page 36 of Bulletin 56, in which the pressure acted to shorten a copper cylinder, were found to be unreliable for measurement of low explosion pressures, because of the unevenness of the copper cylinders and the false records caused by the handling of the instruments. A new design of this type was made, which was more sensitive and better protected from the troubles due to handling, but was abandoned temporarily on account of its cost and the insufficiency of result as compared with the complete and accurate data obtainable with the improved manometer.

MERCURY TYPE.

Another type of maximum-pressure gage tried in some of the earlier tests consisted simply of a glass capillary tube of about

$\frac{1}{8}$ -millimeter bore, sealed at one end. The inside of this tube was silvered and a small drop of mercury placed in the open end. The mercury when driven up the tube dissolved the silver from the glass, showing how far the drop had traveled. The maximum pressures of a dust explosion, however, are generally of such short duration that the mercury does not have time to act on the silver coating.

When the new Bureau of Mines manometer, giving a continuous record of pressure, proved satisfactory, there was no further need of gages that would give only the maximum pressure, and their development was discontinued.

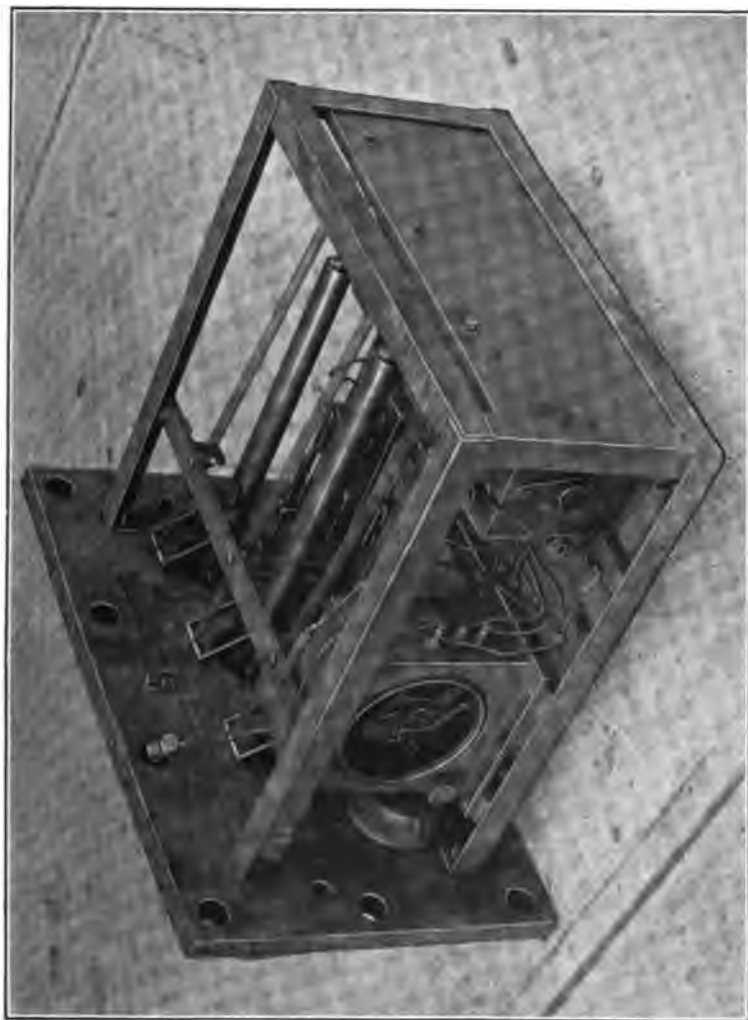
SAMPLERS.

BUREAU OF MINES AUTOMATIC SAMPLER, MODEL A.

The automatic sampler, model A (Pls. VIII and IX, A), which was designed and built in the instrument shop of the bureau, comprises three brass bottles, which are evacuated previous to the test and then automatically opened for a very short time during the explosion. One end of each bottle is closed with a thin glass plate. On the releasing of an electromagnet a steel striker is driven against the glass, breaking it and allowing the gases to rush into the bottle; 0.05 second later a rubber stopper is driven into the open end of the bottle and locked in position, thus tightly closing it. The magnets are controlled by three small batteries carried in the sampler. The magnet of the first bottle is connected in series with a flame circuit breaker (tin-foil), which may be placed anywhere desired. When the first bottle is released, a clock is also released, which opens the circuits of the other two bottles at any predetermined time interval after the first one. The second and third bottles are generally set to operate in 0.25 to 0.5 and 1 to 2 seconds, respectively. The capacity of these bottles is 140 c. c., and the pressure of the sample in the bottle varies from 300 mm. of mercury to above atmospheric pressure. The purpose of taking a series of gas samples was to study the progressive combustion of coal dust, and the distillation of gases therefrom, momentarily before, during, and after the passage of the flame of the explosion.

BUREAU OF MINES AUTOMATIC SAMPLER, MODEL C.

The automatic sampler, model C, built in the Bureau of Mines instrument shop, was designed with the object of obtaining a sampler which (1) could be controlled from the laboratory, (2) would remain open only momentarily in taking a sample, (3) would lock securely after taking it, and (4) could be placed when desired in the central part of the entry. It was thought that in some tests the samples taken at the side of the entry, being screened off by a curtain of



BUREAU OF MINES AUTOMATIC SAMPLER, MODEL A, SHOWING DETAILS OF CONSTRUCTION.



A. BUREAU OF MINES AUTOMATIC SAMPLER, MODEL A, INSTALLED IN THE EXPERIMENTAL MINE.



B. BUREAU OF MINES AUTOMATIC SAMPLER, MODEL C, INSTALLED IN THE EXPERIMENTAL MINE.

unburned coal dust, were not fairly representative of the explosion gases. To accomplish the fourth object, the sampler can be placed in one end of a 5-inch iron pipe projecting into the entry (see Pl. IX, *B*).

Details of this sampler are shown in Plate X. The sample bottle is a brass tube 2 inches in diameter and 9 inches long, actuated by a mechanism in the rear. This mechanism pushes the tube outward, breaking the glass stopper in the end and pressing this end against a stationary rubber stopper (see Pl. X). The motion is in two phases. A sliding movement of one-fourth inch, caused by a large coil spring surrounding the bottle, breaks the glass and permits the gases to rush into the sampler. Further advance, about one-half inch, is controlled by a drum which is at the rear of the bottle and rotates on a screw of one-fourth inch pitch. The movement of this drum permits the bottle to be closed by the large spring mentioned above, and continues until the stopper is jammed in place. The low pitch of the threads of the drum acts as a lock upon the bottle after the sample is taken, preventing any inward leakage of air during subsequent handling. The pressure within the bottle is generally below atmospheric pressure, because of the short time interval during which the sample is taken.

A number of these samplers may be placed at one station and operated successively by a periodic timing device in the laboratory. The interval between samples may be adjusted from one-tenth of a second to five or six seconds. The first bottle may be operated by the burning out of any one of the tin foils (see p. 40) now used for determining the flame velocity. The timing device is shown belted to the chronograph at *d*, Plate V, page 39.

MISCELLANEOUS DEVICES.

FLAME INDICATORS.

GUNCOTTON TUFTS AND SAFETY MATCHES.

Two methods for determining approximately the extent of the flame between tin-foil stations and providing supplementary checks to the melting of the tin-foil circuit breakers have been employed in most of the tests; one of these was the use of guncotton tufts and the other of safety matches. The guncotton tufts are more sensitive than safety matches, as guncotton will ignite at temperatures between 175 to 185° C., or much below the temperature of visible flame.

The hot gases resulting from an explosion, following the extinction of the flame, will have sufficient temperature to ignite the guncotton and matches. However, at the terminus of the explosion the movement of the hot gases is usually so quickly reversed and cooling is so

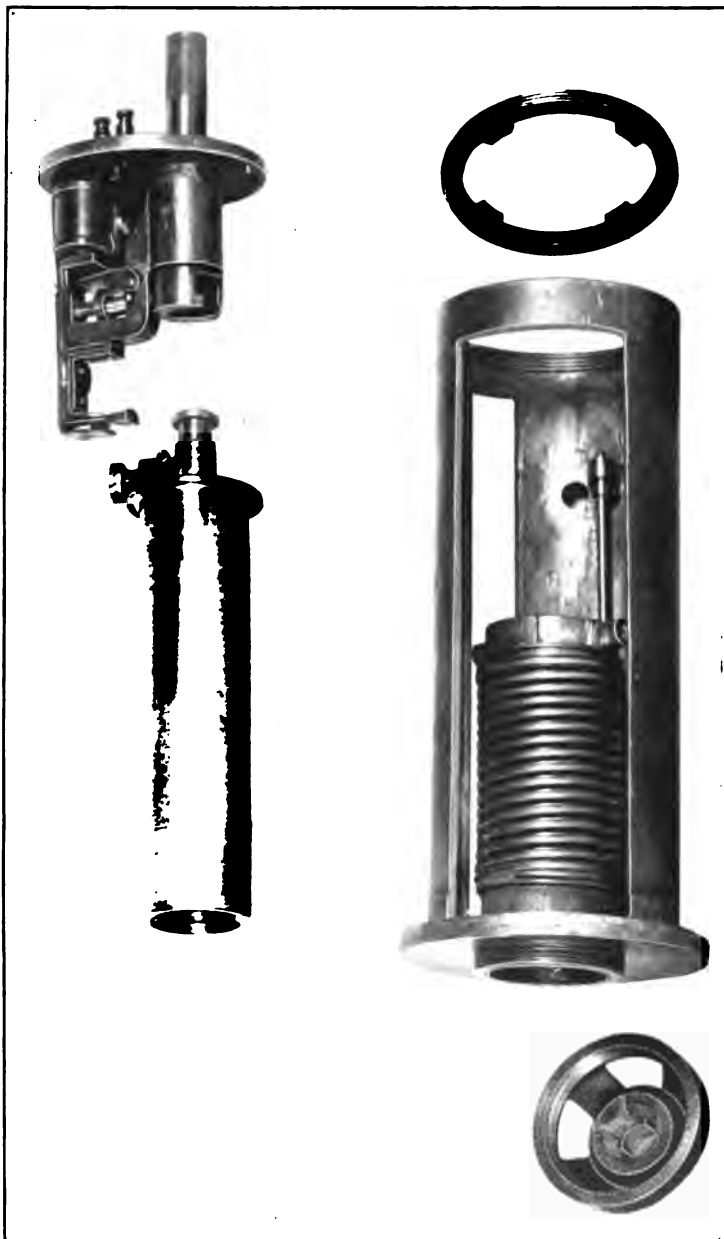
rapid that the use of these devices, to indicate the farthest advance of the flame, has been practicable. Individual guncotton tufts and matches are not always reliable and may be carried away by the violence of the explosion, but when used freely in large numbers and at close intervals they assist in establishing the termination of the flame between tin-foil stations and serve as a check on the foils themselves when these have been ruptured by violence or have been screened by clouds of coal dust or rock dust.

It was a common experience to find the guncotton consumed beyond the matches in the direction the explosion was traveling, in all probability having been ignited not by the flame but by the heated gases projected beyond the point reached by the flame. From experience with both indicators it is believed that the matches give the best rough immediate indication of the actual length of the flame.

The guncotton tufts were hung from wires in the roof at intervals of 25 feet and also from posts set in the rib every 16 feet. Matches were placed at the same points, being inserted in holes in wooden plugs and in the posts so that only the heads projected. In some of the later tests heavy steel wires were strung across the entry about 3 feet from the floor and guncotton tufts hung from these, thus affording an indication of the flame in the middle of the entry as well as at the sides and roof.

PHOTOGRAPH-PAPER RECORD.

A new and more positive device for recording the passage of flame has been used since September, 1915. Sensitized photographic paper behind a glass is held in a $\frac{1}{2}$ -inch pipe coupling. It was found that the most advantageous position for the coupling was at the center of the roof projecting downward. A series of these couplings are placed every 25 feet throughout the zone of the test. The photographic paper when developed after the explosion shows whether or not flame has passed it. The difference between the intensity of the flame where it is strong and where it is dying away is often shown clearly in successive recorders by the relative shades of color of the developed paper. The position the recorder occupied in the mine is shown on the developed paper by the print of a number which was pasted on the glass of the recorder. When the recorders are loaded in the dark room preparatory to making a test, a plug is screwed into the end of each coupling, which protects the sensitive paper from light while being taken to the mine and put in position. After all other lights are out of the mine a man with a nonactinic light takes out all of these plugs. He also puts them back in place before any other lights are taken into the mine after the explosion. This type of recorder has supplanted the use of guncotton and matches within the test zone; the latter are still used in more distant parts of



BUREAU OF MINES AUTOMATIC SAMPLER, MODEL C, SHOWING DETAILS OF CONSTRUCTION.

the mine to cover the possibility of the advance of the explosion farther than intended.

EXPLOSION-TEMPERATURE MEASUREMENTS.

Attempts were made to measure the temperatures of explosions by various methods, but these have not been successful on account of the short duration of the temperature. One method, tried to obtain a rough idea of temperature, consisted of using foils of various metals. If certain foils were fused while others were not, the temperature was at least as high as the melting point of the foil fused.

Foils of platinum, nickel, gold, silver, and aluminum were tried. Platinum melts at $1,755^{\circ}\text{C}$.; nickel, $1,452^{\circ}\text{C}$.; gold, $1,063^{\circ}\text{C}$.; silver, 963°C .; aluminum, 659°C .; and tin, 232°C . All of the foils were of the same thickness as the tin foils used for flame-velocity records, except the nickel foil, which was slightly thicker. These foils were placed on the rib on wood blocks similar to those used for tin foils at the stations, as described on page 40. The foils were tried in 10 tests. In one test the aluminum, silver, and gold fused; in two other tests the aluminum only was fused. For making accurate comparison between tests close regulation of the time of exposure is necessary, but the duration of the flame is so short that no attempt was made to control the time in these tests. The explosion in which the gold was fused (test 330) was initiated in a room off No. 1 left butt, the foils being placed on a post in the room. The fusion was probably caused by a temperature slightly in excess of the fusing point, but of relatively long duration, rather than by a temperature much higher than was attained in the other tests.

These foils were also tried on a block arranged to slide on a long wire, but the travel of the slider could not be made to coincide with the travel of the flame, and the scheme was abandoned.

It will be noted that the melting point of aluminum, 659°C ., is much lower than the temperature of a flame or body bright enough to affect the photographic flame-indicators. As the aluminum fused in only a few of the tests, this method of temperature measurements was discarded.

MANIPULATION OF INSTRUMENTS DURING TESTS.

When the engineer in charge of the test is assured that every man is out of the mine and in a safe place, he unlocks the safety cut-out box near the mine mouth and then sends the keys to the laboratory, at the same time telephoning that everything is ready. When this message is received at the laboratory all instruments are tested; the shot-firing safety box is unlocked and its circuit tested for continuity. If everything is right, the signal is given the engine room and three short blasts of the whistle give a preliminary warning. All switches, except the main distributing switch and the two

switches in the shot-firing and ignition circuits, are then closed, and a single blast of the whistle gives a final warning. Twenty-five seconds after the whistle stops blowing the shutting of the main switch starts all instrument motors and closes all circuits, except the shot-firing and ignition lines. At 29 seconds the ignition circuit is closed, and at 30 seconds the shot-firing switch is closed, firing the cannon shot. About 10 seconds later the manometer motors are stopped. The chronograph pens are raised from the paper when they have run as far as possible without interfering with the records of neighboring pens, and then all switches are opened. Two blasts of the whistle indicate that the test is over.

The chronograph records are then fixed, removed, and the time marks numbered. As soon as the gases have cleared out of the instrument stations in the mine, or on the following day, the paper records are removed from the manometers and fixed in a similar manner. The manometer films and flame recorders are then taken from the mine and developed in the laboratory. The gas-sample tubes are removed promptly from the mine, the samples transferred to other containers, and sent to the bureau's gas laboratory at Pittsburgh for analysis.

RECORDS AND CURVES.

MEASURING AND PLOTTING THE RECORDED DATA.

The time records on the chronograph sheets are counted, and the manometer curves are measured and transferred to time and pressure coordinates. The B. C. D. manometer records are measured on the measuring drum described in Bulletin 56. The photographic manometer records, which are on a larger scale and do not have to be measured as accurately as the others, are read on a special instrument designed in the bureau's laboratories. It consists of a board 6 inches by 20 inches in size with a steel scale along one of the long sides. Spring clips at the proper points hold the film alongside the scale. A slider carrying cross hairs slides on a vertical scale, which in turn slides on the horizontal scale. The scale divisions are in millimeters; a vernier on the slider permits vertical readings to one-tenth millimeter. This machine is less trying on the eyes than the B. C. D. measuring drum and is much faster to operate. All of the records of one test are then plotted on one sheet, as described below.

DESCRIPTION OF CURVES.

The distance traveled by the explosion is plotted along the vertical axis. Where there are two paths, the point of ignition is placed in the center of the sheet, one path being plotted upward and the other downward. Such points as are common to both paths are plotted in both directions. Bends in the path are plotted in straight lines, the

distance being measured along the center line of the entries. Figure 3 shows the curves for explosion test 301, which are typical. The diagram at the left of the curves shows the paths taken by the explosion and the dust loading along these paths. The first 50 feet of the explosion path is represented in both directions from the igni-

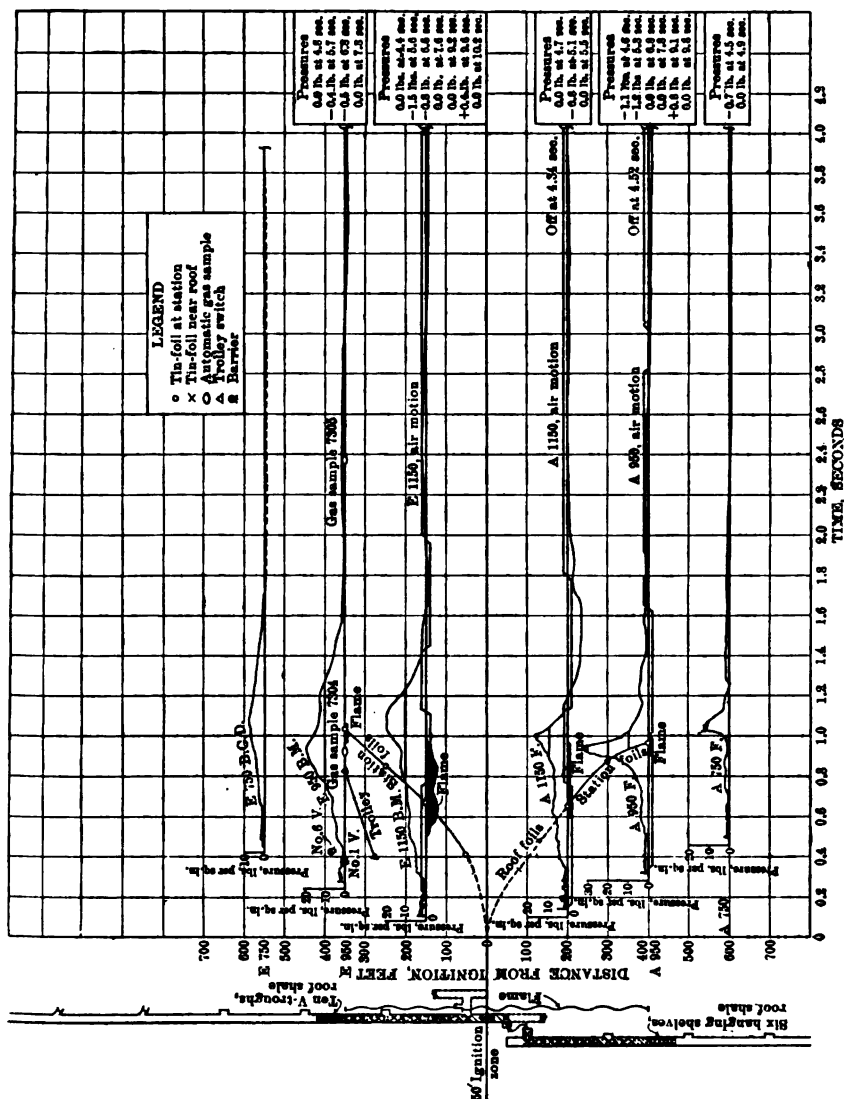


FIGURE 3.—Typical instrument record curve sheet (test 301).

tion point, which is represented by a heavy arrow. Pulverized Pittsburgh coal dust was distributed in this 50-foot length of entry from the face, which in this test served as the starting zone, as explained subsequently in this bulletin. Through the test areas mixed dust was distributed—50 per cent coarse dust from the

Indiana No. 5 coal and 50 per cent coarse shale. The time intervals, as measured from the instant of ignition, are plotted along the horizontal axis. The pressure curve for any station is shown as if it had been projected at the proper place in a plane vertical to the surface of the plotting sheet and then revolved until it rests on the surface of the sheet, with the upper end toward the top.

In this test the point of ignition was at the face of the main entry (E 1300). One path of the explosion followed was along the entry toward the entrance, until it was stopped by the barrier at E 950, 350 feet from the starting point (see fig. 1, p. 14). The other path, branching off 50 feet from the starting point, was through the cut-through at E 1250 and out the air course, until the explosion was stopped by the barrier on that side. This barrier and other barriers will be described later.

In this curve the first path is shown in the upward direction and the second one downward. Reference to the plan of the mine (fig. 1, p. 14) and the curves (fig. 3) will show that station E 1150 is at the point 150 feet from the zero line. At this point the flame curve shows that the tin foil burned out 0.67 second after the ignition wire across the mouth of the cannon was broken. The reader will also notice that at the coordinate, representing 1.10 seconds, the pressure rose to 19 pounds per square inch above atmospheric, whereas at 1.80 seconds the pressure was about 1 pound per square inch below atmospheric pressure. The heavy black mark extending from the ordinate representing 0.50 second to that representing 1.00 second shows the passage of the flame as actually photographed by the same manometer upon which the pressure curve was obtained. The height of the mark represents roughly the intensity of the flame.

Moving 200 feet farther from the explosion origin to station E 950, the curve here shows how the pressure has developed in traveling out to this point. As the rock-dust barrier stopped the explosion here, there are no further points on the flame curve (marked "Foil"). The small broken circles at 0.37 second and 0.42 second show the time at which the barrier operated. The reader will observe that the flame did not reach the barrier until about 0.8 second after it had dumped, discharging its load of rock dust, because of the shock wave from the shot or ignition zone having made the barrier operate.

The straight line, offset one scale division from the E 1150 base line, indicates the direction of movement of the gases when the velocity is 50 feet per second or more. Position of this line above the base line indicates that the gases were moving toward the entry mouth; position below the line indicates movement toward the face. The reader will notice that the gases started outward with the shock wave at 0.23 second and continued in that direction until 0.75 second, when they started in the other direction.

CHAPTER III.—STUDY OF EXPLOSIONS OF PURE PITTSBURGH COAL DUST AND SOME OF THE PHYSICAL PHENOMENA COMMON TO EXPLOSIONS.

INITIATION OF A COAL-DUST EXPLOSION.

In order to initiate a coal-dust explosion two requirements must be met: A dense cloud of the inflammable dust must be made and a source of ignition supplied. In most of the experimental explosions both of the required conditions were supplied by the same means—a blown-out shot of black powder from a steel cannon. The length of flame from the usual charge of 4 pounds of FFF black powder is about 20 feet.

SHOCK WAVE.

The firing of the originating shot sets up a so-called "shock wave," which travels through the air in all directions at a velocity of 1,100 to 1,200 feet per second, depending on the distance from the origin, the temperature and humidity of the atmosphere, and the nature of the passageway. The shock wave is essentially the same as a sound wave, and, as will be noted, has the same longitudinal velocity through the air, but has a low period of vibration. It is important to bear in mind that the velocities mentioned above refer to the velocity in the air or gas. If the air or gas is in motion, the velocity of the shock wave with reference to a fixed point will be greater or less by the amount of such movement in one direction or another at the time of the passage of the wave.

The curve in figure 4 shows the average velocity of shock waves as measured in a number of tests. The velocity from the origin to station E 1150 and to station A 1150 exceeds 1,400 feet per second; however, along the first part of this distance the shock wave is probably traveling in a medium which is moving in the same direction at a high temperature owing to the local effect of the blast or cannon shot. It is interesting to note that the velocity of a wave advancing through the cut-through and out the air course, although passing around two right-angle turns, is as great as that of a wave advancing out the straight entry. The following table gives the time of passage of the shock wave at various points and also the velocities between stations when the origin is at station E 1300:

Average time values for shock wave when cannon is at station E 1300.

Station.	Distance from origin.	Time.	Velocity.	Station.	Distance from origin.	Time.	Velocity.
	<i>Feet.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>		<i>Feet.</i>	<i>Seconds.</i>	<i>Ft. per sec.</i>
E 1150.....	150	0.107	1,198	A 1150.....	200	0.142	1,136
E 950.....	350	.274	1,143	A 950.....	400	.318	1,111
E 750.....	550	.449	1,130	A 750.....	600	.498	
E 550.....	750	.625					
E 350.....	950	.804					

The shock-wave pressures, as measured by a recording apparatus 150 feet from the origin, average about 3 to 4 pounds per square inch (at right angles to the direction of travel), but in some tests pressures of more than 5 pounds per square inch have been noted. The accompanying curve (fig. 5) shows the appearance of a typical record; the vertical coordinate represents the pressures in pounds per square inch and the horizontal coordinate the time in seconds.

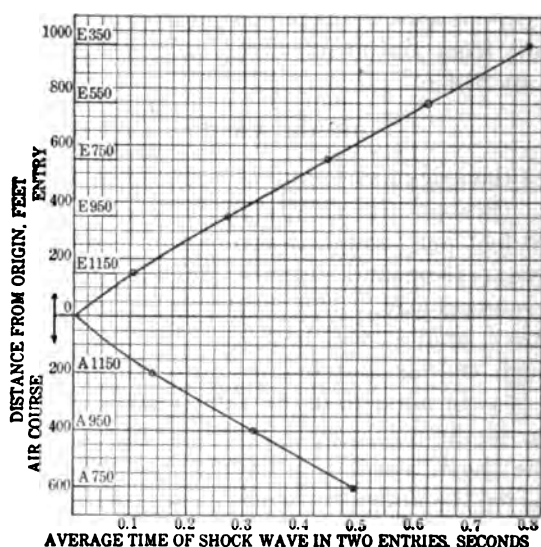


FIGURE 4.—Curve showing average velocity of shock waves in explosion tests.

The first part of the curve represents an abrupt rise of pressure from zero to 6.2 pounds per square inch; a sharp trough follows and then alternating peaks and troughs, which are caused by the vibration of the pressure disk of the apparatus, the correct pressure being the mean of the extreme points of the vibration.

The shock wave from the cannon has a higher velocity than that of the initial explosion of coal dust; the latter at the start is relatively slow, but rapidly accelerates in an explosion that propagates. On the other hand, the shock wave is practically constant in velocity but rapidly diminishes in strength, its pressure being barely discernible on the manometer records at a distance of 700 or 800 feet from the cannon. Under favorable conditions a dust explosion rapidly increases in velocity until at 300 or 400 feet from the

origin the explosion may attain a higher velocity than the shock wave and possibly may overtake it, but this has not been the case within the length of the experimental mine entries.

MECHANISM OF A COAL-DUST EXPLOSION.

As described in Bulletin 56 ¹⁹ and as further discussed hereinafter, the standard explosion tests were initiated by a shot from a steel cannon placed on the floor at the face of the main entry, coal dust being distributed on a platform in front of the cannon and upon side

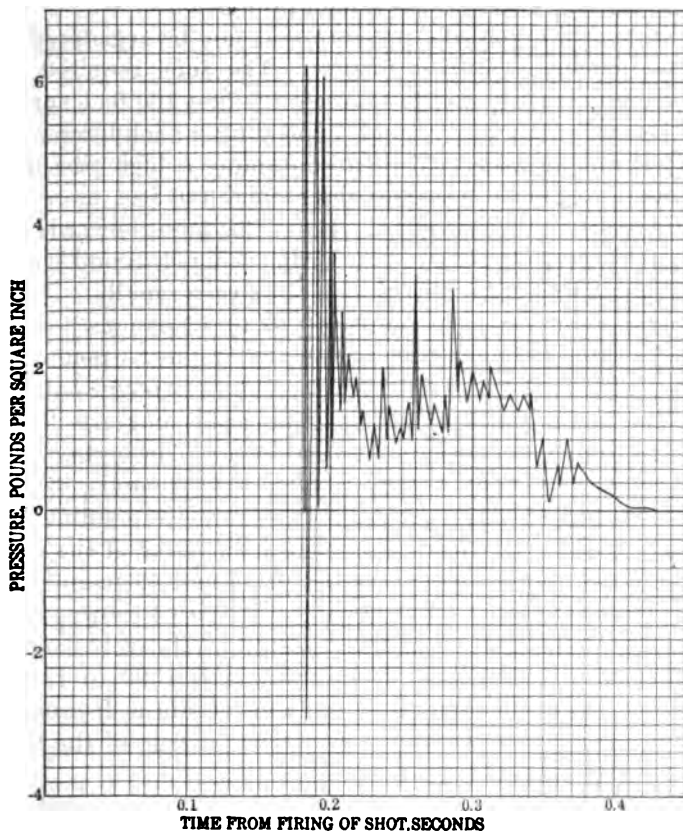


FIGURE 5.—Typical shock-wave pressure curve for standard blown-out shot, as recorded by French manometer at station A 1150, the cannon being at the face of the opposite entry, 200 feet distant.

shelves along the ribs. In the initiating zone a surplus of coal dust was used to insure there being sufficient combustible for consuming all the oxygen present in the corresponding length of entry. The characteristics of a coal-dust explosion taking place under these standardized conditions are discussed in the following paragraphs. A paper ²⁰ containing a similar discussion was presented before the Institute of Mining Engineers, Great Britain, in June, 1915.

¹⁹ Rice, G. S., and others, First series of coal-dust explosion tests in the experimental mine, 1913, p. 28.

²⁰ Rice, G. S., American coal-dust investigations. Paper presented before the Institute of Mining Engineers, Great Britain, June 1, 1915.

IGNITION OF COAL DUST AND COURSE OF AN EXPLOSION.

Part of the dust on the platform in front of the cannon is raised by the blast, and is ignited by the flame from the explosive. This dust burns rapidly, and other dust raised by the eddying currents is carried into the zone of combustion. So far as the pressure manometers show, the interval before the pressure produced by the burning dust becomes appreciable is one-half second, more or less, and is much longer if the dust is feebly explosive. If the zone of dust loading is short or if the dust mixture has a high proportion of ash, so that the mixture is barely explosive, pressure will not be registered on the nearest manometer, 150 feet distant. The time required for the flame from the burning dust to traverse the first 100 feet varies from one-half to more than one second, depending on conditions. If the explosion is fed by pure coal dust containing a high percentage of volatile combustible, it traverses the second 100 feet more rapidly, usually in less than half a second. From this point onwards the rate increases until a velocity of more than 2,000 feet per second is attained, and with highly explosive dust the pressure rises rapidly. With dust loaded in a single entry, pressures of 10 to 15 pounds²¹ have been developed at the station 150 feet from the origin, 63 pounds at 350 feet from the origin, 73 pounds at 550 feet, and 119 pounds at 750 feet.

With dust loading in both entries, the explosion starts faster and higher velocities and pressures are attained. The highest pressure that has been recorded at station A 950 was 127 pounds, 115 pounds being recorded in the same explosion at the corresponding point in the parallel entry. Barriers extinguished the flame of the explosion at these points, and the pressures fell to 33 and 48 pounds, respectively, at the next station in each entry. Figure 4 shows the instrument records of the test. This test utilized a relatively coarse semi-bituminous coal dust, loaded from stations E 1300 to E 950 and A 950, these high pressures being built up within a distance of 350 feet and occurring simultaneously with the passage of the flame 0.8 second after the shot was fired.

Higher pressures have unquestionably developed in several of the tests, judging from the disruptive effect at certain points in the passageway where there were no pressure manometers and from the damage to the manometers. In one instance a B. C. D. manometer (described in Bulletin 56, p. 57) equipped with a 100-pound spring and installed in station A 950 had the plunger completely blown out of the oil box, the spring being permanently bent. The record was destroyed but the pressures could hardly have been less than 150 pounds per square inch.

²¹ The retonation-wave pressure may be higher than the pressure measured at the time of passage of the explosion flame past any given station.

In several tests the Bureau of Mines manometers have had the light spot driven over the edge of the film by high pressures, and in two tests the mirrors were thrown off the pivots and other damage caused. In one of these tests it was estimated that the recorded pressure was 145 pounds or more, but this could not be definitely determined.

POSSIBLE MOVEMENT OF AIR TOWARD AN EXPLOSION.

A few mining men have held that because oxygen is essential to combustion there is an inrush of air in the face of an advancing explosion, which carries the dust into the zone of combustion and supplies additional oxygen to the flame. This opinion was urged so strongly that the attempt was made to determine by appropriate instruments whether or not there was any underlying truth in the theory. The air-direction indicator described on page 43 was constructed for this purpose. In figure 3 (p. 57) the forward and backward movements of the gases of the explosion are indicated. No evidence was found to support the idea that in a mine with an air circuit there is an immediate inrush of air toward an advancing explosion. A moment of no movement succeeds the shock wave from the cannon, then an outward movement follows, caused by the explosion. This outward motion continues until the explosion has gone its course unless strong retonation waves follow the passing of the flames and cause temporary reversal toward the origin. After these waves have passed, movement in the outward direction is resumed and continues until the gases cool and contract, causing the air to rush in behind them. If the pressure of an explosion does not materially rise in its course, retonation waves are not detected, so that the movement of gases is continuously outward until they cool, the cooling causing an inward rush.

AIR AND GAS VELOCITIES.

It has now been well established that the velocity of an explosion is the sum of two different movements. One of these is the velocity of the body of air and gases, first set in motion at the origin of the explosion (if the explosion increases in intensity, the velocity of this gaseous body increases); the other is the movement of the zone of combustion within that moving body, analagous to the wave movement in running water, as on the surface of a rapidly flowing river. In some instances the velocity of the moving gases may be negative for a period, so that the flame of the explosion is momentarily stationary. Taffanel has called these moments "periods of equilibration." They are most likely to occur in galleries closed at one end, and have also been observed at the experimental mine under certain conditions. When the loadings in the two parallel entries are of

different lengths and the explosion through the longer loading is sustained sufficiently, then there appears to be momentarily a checking or backward movement in the shorter zone in the parallel entry. However, if the explosion is very strong and extensive this condition is not observable. In places where the flame is stationary, or nearly so, with reference to the walls, although advancing with reference to the gas and dust, there is usually a local deposition of a large amount of coked dust if an ample supply of pure coal dust is present. In order better to study the air movements that are not recorded by the wind vane, an arrangement was devised comprising a wire like a trolley wire, on which runs a disk of metal and rubber sheeting about 4 inches in diameter. There is some slight friction from the sliding of the disk, but not enough, it is believed, to affect greatly the results. This device, described in detail on page 45, is also valuable in indicating, with low-velocity explosions, what leverages and sizes of vanes are necessary for tripping the various mechanically operated rockdust barriers. The air velocities as indicated by these instruments are comparatively low as compared with the velocities of the flame. In a slow-moving explosive with mixed dust (test 197) the air velocity as given by the vane was 73 feet per second as compared with a flame velocity, for the same distance, of 108 feet per second; in test 206 the air velocity was 179 feet as compared with a flame velocity of 495 feet. In rapid explosions the velocity of the gases increases. In test 161 the rate was 764 feet per second as compared with a flame velocity of 2,175 feet. Owing to the variable factors introduced by retonation waves, reflected waves, and other unknown variables, it has not been found possible to determine any constant ratios between air and gas velocities and flame velocities.

RETONATION WAVES.

When highly explosive coal dust is uniformly loaded, the pressure of the explosion wave, so far as can be determined within the length of the passages of the experimental mine, keeps rising from point to point. Also, as this increasing pressure wave advances what Prof. H. B. Dixon has termed "retonation waves"²² are thrown off and travel backward through the hot gases toward the origin; in other words, pressure waves from the area of high pressure proceed in either direction toward the areas of lower pressure. Evidence of violent movements in the direction opposite to that which the explosion is known to have traversed has been obtained at the experi-

²² The term *retonation wave* is not here used with the strictly limited definition of a wave movement of maximum velocity as defined by Dixon (Record of first series of British coal-dust experiments, p. 150) in connection with wave movements in explosions of gaseous mixtures, but is used in the more general sense to designate any high-pressure wave traveling back toward the origin from the point of highest pressure to regions of lower pressure.



A. CAR AFTER TEST 46, HAVING BEEN THROWN 147 FEET AND OVERTURNED AND ITS LOAD DUMPED DURING MOVEMENTS.



B. FACE OF MAIN ENTRY AFTER TEST 20, SHOWING DÉBRIS CARRIED INWARD BY RETONATION WAVES.



A. CONDITION OF LAST CUT-THROUGH AFTER TEST 20.



B. CONSTRUCTION OF HEAVY STOPPING USED IN TESTS IN THE BUTT ENTRIES.

mental mine by means of large wooden blocks, marked for identification, placed at regular intervals. In an explosion of increasing intensity it has been found that up to a point at which the pressure either became uniform or fell, the movement or throw of the loose objects was inward; but from the point where the maximum pressure was reached they were thrown outward. The same phenomenon has been demonstrated in some tests by placing loaded mine cars at intervals along the mine passageway. Wherever the crest of the pressure wave was rising the cars were moved toward the origin, although they may have moved outward before moving inward. In one instance (test 46) a loaded car was thrown 147 feet toward the origin of the explosion and was overturned in its passage, as was indicated by scars on the roof. In the same test two other loaded cars, which had been placed farther outby, were also thrown inby. (See Pl. XI, A, herewith and figs. 13 and 14 on pp. 81, 83.)

Plate XI, B, a photograph taken at the face of the main entry after one of the tests (No. 20), also illustrates the effects from retonation waves. The pile of broken boards is the remains of a series of cross shelves placed in the entry, from the face to station E 1050. The heavy blocks were also carried in from outby. In this test the shot was placed in the coal, the shattering of the face indicating its original position.

Many of the explosions of readily inflammable dust mixtures with rising pressures have been of interest in showing that retonation waves have traveled backward toward the origin. In some instances these waves can be identified as passing into the adjoining entry through the last crosscut, thus following the path of the original explosion wave in that entry. The retonation waves apparently travel at the rate of shock waves through the heated gases, and therefore at a higher rate than through air at ordinary temperatures. As the temperatures and velocity of the moving gases are not known with precision, it is not possible at present to tabulate the the velocity rates of the retonation waves.

The movement of the retonation waves in tests at the experimental mine is indicated in the diagram shown in figure 10 (p. 74), which is plotted with reference to time and to distance from the origin of the explosion. The zero line on the base line of each manometric curve is placed at its appropriate position in regard both to the distance from the origin and to the time from the firing of the shot. The pressure curves are represented in the plane of the plan view; therefore each point in the curve must be referred to its respective base in considering its relation to the passage of the flame or to the movement of the waves from point to point.

PRESSURES DEVELOPED BY COAL-DUST EXPLOSIONS.

In the investigation of explosion disasters it is frequently a matter of speculation as to what pressures may have been developed to produce the disruptive effects observed. Suppose an explosion has attained a gage pressure ^{22a} of 105 pounds per square inch, or about eight atmospheres; then there will be eight times as much oxygen present in a cubic foot of air space as there was at the initiation of the explosion. Hence if there is enough inflammable dust present, and no more, to combine with all the oxygen the energy generated per unit of space by the combustion will be about eight times greater than at the beginning of the explosion. When a coal-dust explosion attains high velocities and pressures, the compression of each successive film or vertical layer of air ahead may be adiabatic, so that the temperature of the air is instantly raised to the point of ignition of the contained dust; therefore actual transfer of heat from point to point by radiation and conduction, which is the probable action at the beginning, may not take place when the velocity of an explosion is more than 2,000 feet per second and the pressures exceed six atmospheres. The limit of cumulative energy locally developed by a coal-dust explosion appears to be when a balance is attained between the amount of pure coal dust that can be brought into suspension with reference to the oxygen present in a unit of space and the amount of damping agencies, such as inert dust, coarse coal dust, and excess of coal dust for the oxygen present.

The wide range of explosibility of coal dust is one reason why the dust is such a hazard in mining. The minimum amount of dry pure dust which insures propagation is so small—0.05 to 0.08 ounces per cubic foot, or 50 to 80 grams per cubic meter—as to be hardly noticeable in a mine; on the other hand an enormous excess of coal dust does not prevent propagation. It may slow up an explosion, until surplus dust drops out, and cause feeble continuance until more favoring conditions occur in some distant part of the mine where the explosion may again develop violence.

DEVELOPMENT OF STANDARD IGNITION CONDITIONS.

The development of standard conditions of ignition for the experimental tests, in order to insure that an explosion could be obtained at will and that a repetition of a given test would cause similar results, was a problem that gave considerable trouble and required many trials before the final arrangement was adopted.

In the first explosions made in the experimental mine ignition was caused by a blown-out shot of FFF black powder weighing usually from 2 to 3 pounds. The charge was placed either in a bore hole in the solid coal, cased with steel pipe to insure getting a blown-out shot

^{22a} Above sea-level atmospheric pressure.

instead of a breaking shot, or in a steel cannon having a bore hole 2½ inches in diameter and about 21 inches long. Shots loaded by the former method usually caused ignition, but the casing pipe was split and more or less coal at the front of the hole blown away, making uncertain what part of the energy of the blast was expended in the air. The use of the cannon proved preferable as a method more likely to give a uniform impulse, because practically all the energy of the shot is expended in the atmosphere when fired from a cannon. A further objection to placing the shot in the face was that the breaking of the coal necessitated "squaring up the face" after each test, and in time this changed the conditions with reference to the irregularities of the ribs, roof, and floor and of the places turned off the entry. In the tests by cannon a 16-foot platform, 4 to 5 feet wide, was placed in front of the cannon, just below the bore hole and about 18 inches above the floor.

In later tests, trials were made of initiating the coal-dust explosions by an explosive mixture of fire damp confined at the face of the main entry behind a paper diaphragm 50 feet from the face. The tests showed that this method could be used for initiation, but it involved so much difficulty in getting an exact mixture to obtain uniform results, and also involved such serious hazards to the personnel, that it was abandoned in favor of the method of cannon-shot ignition. These tests are described on page 174.

In the tests of the first series the face of the entry varied in position from 68 to 93 feet ahead of the last crosscut. The mine, except at a few points, was free from seepage of water and therefore practically dry; in the humid spring and summer months, however, the air deposited moisture to an extent that interfered with precise testing. Coal dust was laid usually at the rate of 1 pound per linear foot of entry, distributed on side shelves and in some tests on open "book" shelves placed transversely in the entry. No failures were obtained with these conditions.

Before the beginning of the second series the entries had each been lengthened 523 feet, which advanced the face of the main entry to 1,270, 19 feet beyond the last cut-through (see fig. 1, p. 14). Test 19²² was made with starting conditions similar to those used in the first series, the only difference being the wet condition of entry surfaces and the greater distance of the face from the entrance. No explosion was obtained under these conditions.

TEST 20.

In test 20²²—made before representatives of the International Conference of Mine Experiment Stations at Pittsburgh in September,

²² Rice, G. S., International Conference of Mine Experiment Station, Pittsburgh, Pa., Sept. 14-21, 1912, Bull. 82, Bureau of Mines. Test made Sept. 20, 1912.

1912—the cannon was placed in the last crosscut, and an additional shot was prepared in a cased hole at the face of the entry, with the object of firing both shots at the same time, thus obtaining a larger initial dust cloud. Through a misunderstanding a plank stopping was built behind the cannon in the last crosscut, which would have given the effect, had the stopping held, of a single passageway 1,300 feet in length. Dust was distributed on benches in front of both shots and along the entry side shelves at the rate of one pound per foot. A strong explosion resulted. The stopping behind the cannon in the last cut-through was blown out, probably in part by the shot and more completely by the resulting explosion. The appearance of the crosscut after the explosion is shown by Plate XII, A (p. 64). A brick stopping 18 inches thick in a crosscut opposite the No. 1 butt entry was blown down and the brick scattered both inby and outby in the air course. Near the mouth of the main entry the roof of the reinforced concrete arch was ruptured and lifted. Extensive repairs had to be made following the destructive effects of test 20, and on account of these repairs and certain additions, it was not until June, 1913, that testing was resumed; at this time, owing to seasonal effects, the mine was very damp.

TESTS 21 TO 24.

The source of ignition was a blown-out shot of 2½ pounds of black powder from a cannon at the face of the entry. No explosion resulted, but it is not known definitely whether the failures were due to the method of ignition, or to the coal dust being mixed with 5 to 10 per cent of water, or to the nondistribution of dust in the last open crosscut, as discussed on a subsequent page. As no ignitions were obtained in similar tests with dry dust, the method of ignition was probably the cause of failure.

TESTS 26 AND 27.

The usual igniting shot was fired from a cannon at station E 1299 into a 200-foot zone of pure coal dust. No explosion resulted, probably because of the wet condition of the mine and the release of pressure through the cut-through in which no dust was loaded. In test 27 two dust-raising shots were fired before the igniting shot. These dust-raising shots consisted of 4 ounces of a permissible explosive suspended in the middle of the entry at Station E 1250 and 8 ounces suspended at station E 1200. Figure 6 shows the arrangement of test conditions and the resulting flame as indicated by guncotton tufts. The flame, represented by wavy lines, did not travel to the end of the zone in the entry, so complete propagation was not obtained. It is interesting to note that the flame passed through

the last crosscut and 100 feet out the air course, although no dust had been distributed through this zone; there was, however, some dust adhering to the wet surfaces of this zone. The failure to obtain complete propagation in test 27 was afterwards believed to be due to the partial release of pressure through the 1250 cut-through during the early stages of the explosion. In test 28 dust was placed on the side shelves of the cut-through, as well as in the main entry, and an additional dust-raising shot was fired in the cut-through (see fig. 7). This test resulted in complete propagation throughout the dust zone and 250 feet beyond in both the entry and air course, as indicated by the guncotton tufts. The assumption is that the difference between the results of this test and those of the previous one was due to the loading in the cut-through.

In the earlier testing 1 pound of coal dust was distributed per linear foot of entry, but the loading was increased to 2 pounds per linear foot in order to insure sufficient dust being present.

TEST 33.

In test 33, made July 23, 1913, two cannon were used,

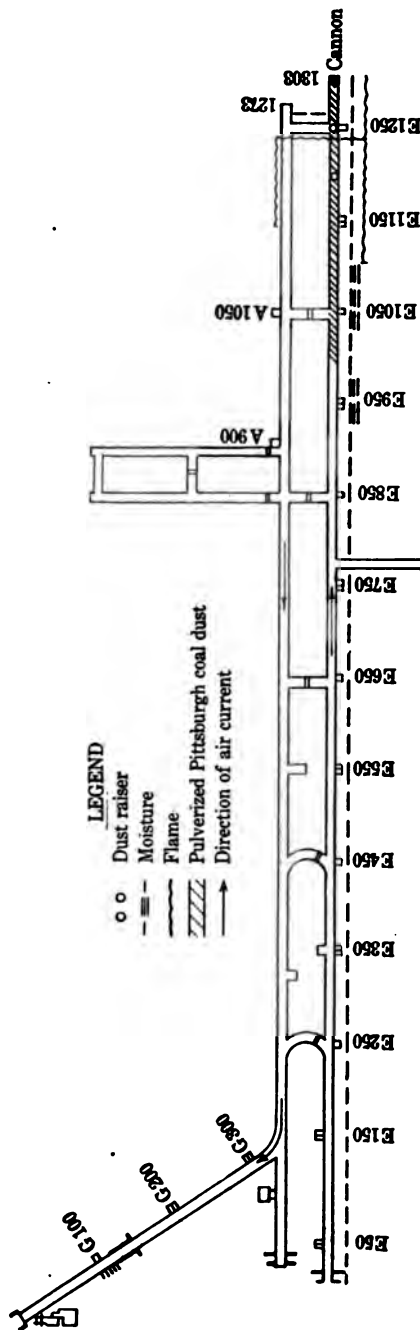


FIGURE 6.—Diagram showing condition of mine as prepared for test 27 and primary results of the explosion, June 30, 1913.

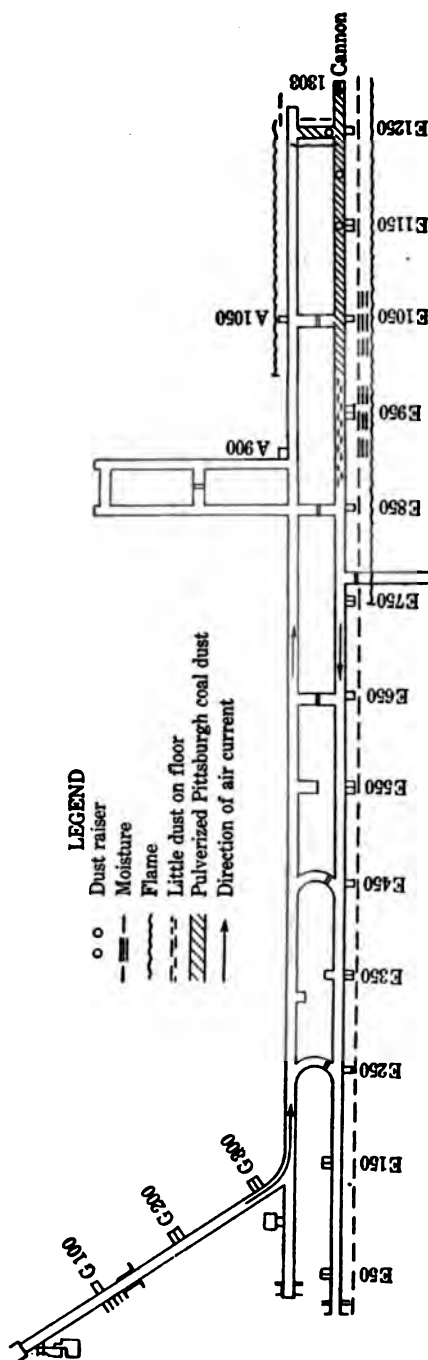


FIGURE 7.—Diagram showing condition of mine prepared for test 28 and primary results of the explosion, June 30, 1913.

one being in the 1250 cut-through and pointing outward diagonally across the entry and the other being at the face of the entry. Fifty pounds of coal dust was placed on a bench in front of each cannon. A high-velocity explosion resulted, indicating that the arrangement would be very satisfactory. This method was used in subsequent tests during the summer when the mine was more or less wet and a strong starting impulse was considered necessary, explosions being obtained in all trials.

About the 1st of October the mine had dried somewhat and was in better condition for standardizing tests; hence, in order to simplify conditions and the interpretation of shock-wave records, it was decided to use only one cannon and to increase the charge of black powder to 4 pounds. No dust was placed in the 1250 cut-through. As successful ignitions were generally obtained with these conditions, this method was used in tests 47 to 61. In test 50, however, no propagation was obtained and the results in the other tests were not consistent. This variation in results is believed to be due to two causes: (1) The elevated bench in front of the cannon was broken and dis-

lodged by the shot in a different way in successive tests, so that the density of the dust cloud was different; (2) the release of pressure through the adjacent open cut-through to the air course varied in extent, depending on whether there was left in the cut-through any dust from previous tests, the combustion of which would maintain the pressure.

CHANGES IN ARRANGEMENTS FOR INITIATING EXPLOSIONS.

As a result of the foregoing tests it was decided to place both the cannon and the dust platform on the floor, the surface of the platform being about 10 inches below the bore hole of the cannon. This position of the cannon was adopted as standard in subsequent tests.

TEST 79.

Beginning with test 79, made on February 2, 1914, the side shelves in the last cut-through were loaded with the same quantity per foot as the dust zone in the main entry, except in test 82, so that the explosion would be more likely to develop about the same pressure in the cut-through in each test, which would cause a more uniform development in the main entry in the early stages of the

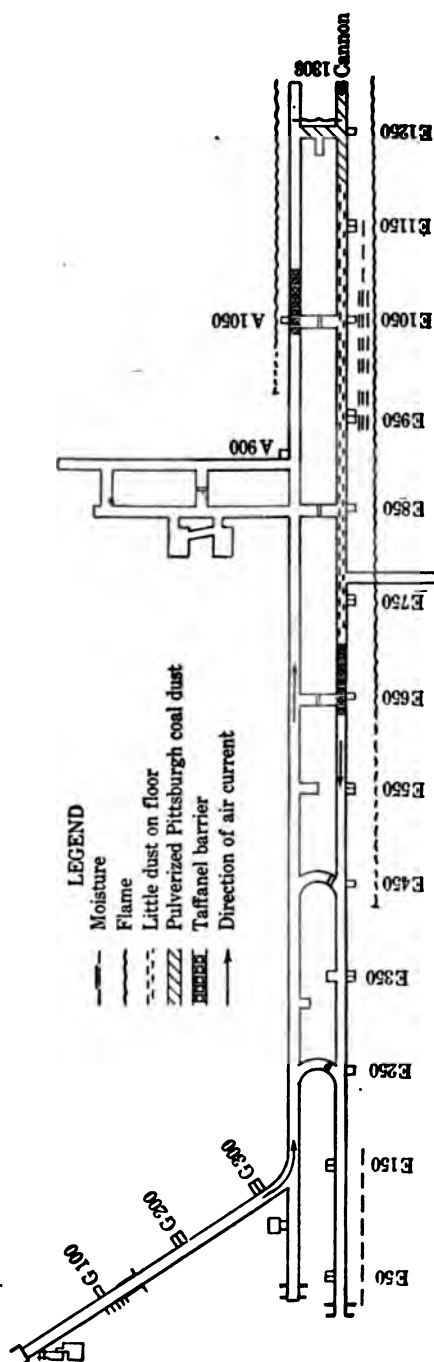


FIGURE 8.—Diagram showing condition of mine as prepared for test 81 and primary results of explosion, February 4, 1914.

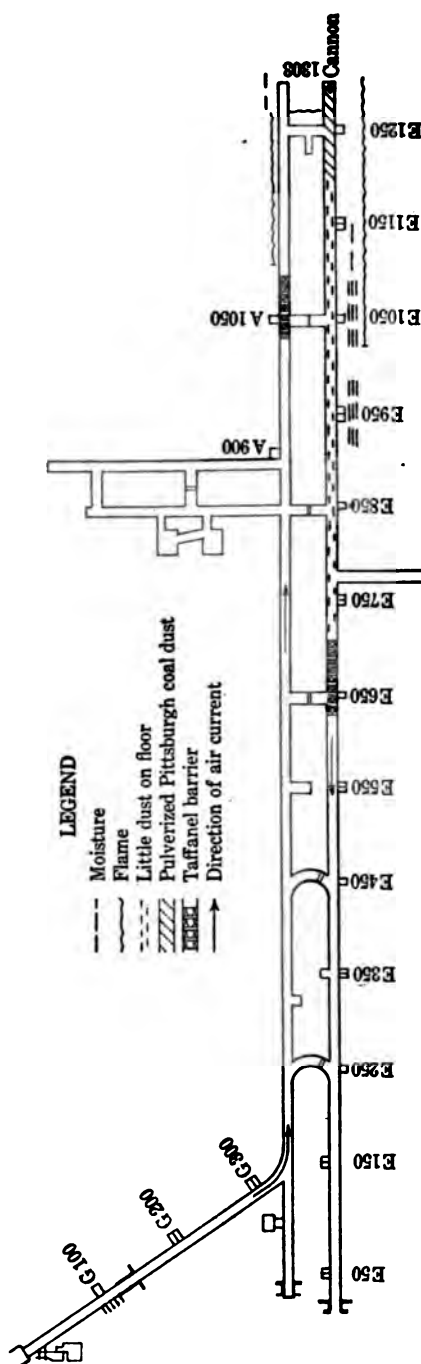


FIGURE 9.—Diagram showing condition of mine as prepared for test 82 and primary results of the explosion, February 5, 1914.

explosion. This arrangement undoubtedly assisted in getting more uniform ignitions in the later tests.

TESTS 81 AND 82.

The effect of loading coal dust in the last cut-through can be seen by comparing the results of tests 81^{23a} and 82, made with 100-foot coal-dust zones (see figs. 8 and 9). The conditions in these two tests were similar, except that in test 81 the side shelves in the 1250 cut-through were loaded with 100 pounds of coal dust, whereas in test 82 no dust was distributed in the cut-through. In test 81 the flame, as indicated by gun-cotton tufts, traveled 500 feet beyond the dust zone in the entry and 150 feet beyond the dust zone in the air course, where it was stopped by the cloud of rock dust from the barriers. Maximum pressures were developed as follows: Twelve pounds at station E 1150, 7 pounds at E 950, 7 pounds at E 750, and 3 pounds at E 550. In test 82 the flame extended only 200 feet beyond the dust zone in the entry and 175 feet beyond the dust zone in the air course. The pressures developed were too small to be measured.

Although the loading of dust in the cut-through

^{23a} See Table 4 (p. 85) giving the results of dustless-zone tests.

probably decreased materially the likelihood of getting poor ignitions, a further development of the loading arrangement at this time made a still greater advance toward getting uniform results. This was the extension of the dust distribution out the air course at least 300 feet. If the loading was symmetrical in the two parallel entries, the explosion would develop in a similar manner on both sides, and as a result the development in the main entry would not be affected in its early stages by release of pressure toward the air course. By the time the explosion would have reached the end of the dust zone in the air course it would have advanced so far in the entry as not to be affected by the checking of the air-course branch. The development of the explosion under those conditions is, however, not exactly the same as in a testing gallery consisting of a single tube with one end closed. The widening of the explosion path at points where the cut-throughs intersect the entries causes wave effects that influence the formation of the dust cloud and the pressure variations of the explosion.

SIMULTANEOUS DOUBLE TESTING.

Beginning with test 104 the double loading in entry and air course was made standard. The curves for test 105 (fig. 10) illustrate the almost symmetrical development of the explosion in the two entries. In this test Pittsburgh coal dust was distributed in both entries from the face of the main entry to station 800 in the main entry and through the last crosscut and out to station 800 in the air course. If allowance be made for the differences caused by the origin of the explosion being at the face of the main entry, the curves for results at stations A1150 and E1150, are very similar, the maximum pressures being 31 and 34 pounds per square inch, respectively, in air course and entry.

During the spring, summer and early fall, as previously stated, the surfaces of the mine are damp and at times very wet. With dust on the damp side shelves adjacent to the more or less wet ribs the cooling effect of the moisture may be of importance in the initial stages of an explosion.

DUST LOADING ON CROSS SHELVES.

The study of this problem led to the important change of trying transverse shelves placed about 1 foot beneath the roof, simulating the crossbars of a timbered entry upon which dust accumulates.

The dust on such cross timbers is dislodged easily by a strong blast of air and, dropping into the path of the explosion, insures a cloud of sufficient density. This arrangement made a decided change in the results, tending to raise the explosibility limits and giving more con-

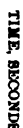


FIGURE 10.—Curves showing results of explosion test 105. Ignition test, no gas, 100 per cent pulverized Pittsburgh coal dust used.

sistent results even when the walls and floor were damp. Accordingly preparatory to making test 115 cross shelves were installed from station E 1250 to stations E 950 and A 750, these being spaced at 10-foot intervals to stations E 1050 and A 1050 and at 20-foot intervals beyond. The dust was loaded at the usual rate of 2 pounds per linear foot of mine entry, but the entire amount was placed on the cross shelves. The explosion was started by firing the usual charge

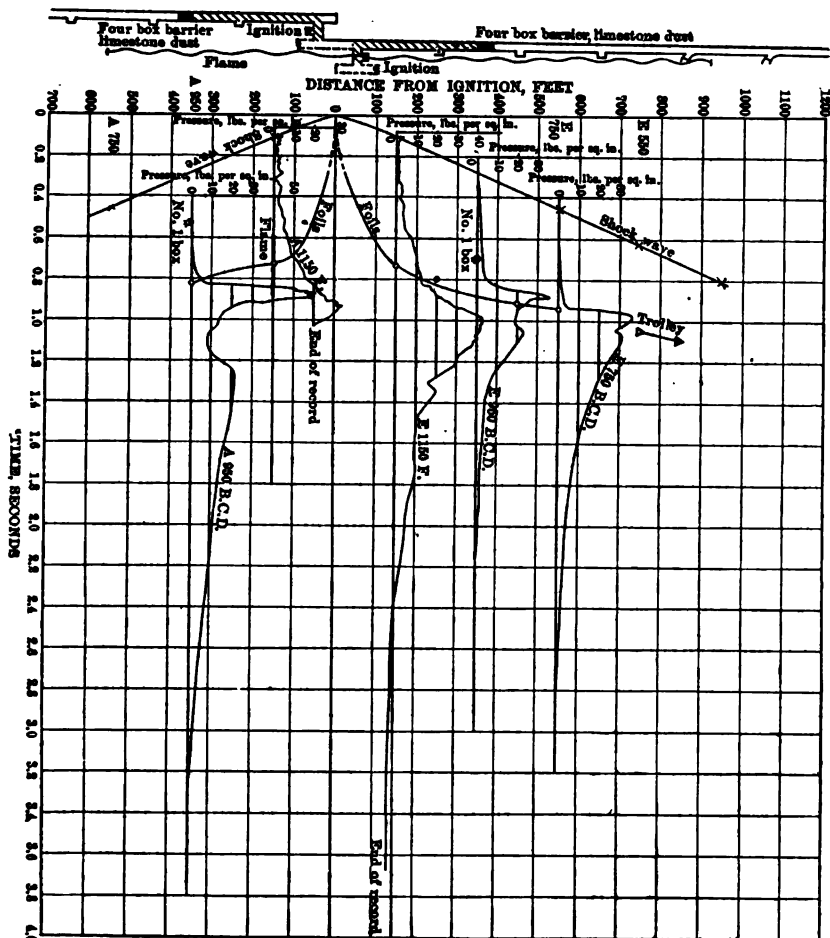


FIGURE 11.—Curves showing results of explosion test 115. Ignition test, no gas, 100 per cent pulverized Pittsburgh coal dust. Test made May 30, 1914.

of black powder from a cannon placed at the face of the offset from the 1250 cut-through (see fig. 1, p. 14). Having the cannon in this locality gives a symmetrical arrangement in both entries to station E 950 and station A 950. The explosion was much more violent for zones of such comparatively short length than had been obtained in any previous test. The pressure records of this test are shown in figure 11. These are discussed more fully in subsequent pages.

The results of this test show that dust placed on overhead cross shelves is far more effective in propagating an explosion than dust on side shelves only. The dust falls through the section of the entry, as previously mentioned, probably making a dense cloud. The formation of the cloud may be assisted further by eddying currents around the shelves, causing more thorough mixing of the dust and air. In mines, it has been pointed out, the fine float dust that collects on timbers is sometimes of the most dangerous character and is easily dislodged to form a cloud. Accordingly the system of using transverse shelves was adopted as standard, and they were installed throughout the main testing zones.

LINING THE TEST ZONES.

As coals from different beds vary widely in regard to the explosibility of their dusts in air, extensive tests of coals from various beds were made in the experimental mine, both to obtain general information on dust explosions and to give specific information about the dust hazards of the individual mines. In such tests it was necessary to insure freedom from contamination by coal dust originating in the experimental mine. Accordingly the roof, walls, and floor in the testing zones, namely, the inner 350 feet of the main entry, the same distance in the air course, and the connecting cut-through, were lined or coated in the summer of 1914, with "gunite," which is a cement-sand mixture thrown violently on to the surface by the "cement gun." An additional purpose was served by the lining in preventing the roof and walls from air slacking. This was the first use underground of the cement gun which is now used extensively both in coal and metal mines for weather and fire proofing. Coating the surfaces has the additional advantage that the dust left from a test can be more effectively removed than it could be from the rougher surfaces of the coal, shale, and ballasted track. In the early tests great difficulty was experienced in getting duplicate results from tests with similar conditions. It is believed, from studying the results of these tests, that this trouble was largely caused by the difficulty of removing completely all dust left from one test before making the following one.

TESTING METHODS ADOPTED AFTER ENTRIES WERE LINED.

After the inner 350 feet of each of the main entries and the cut-throughs had been lined, the following methods were used for testing coal dust, which later were adopted as standard (see p. 179):

1. The igniting shot is fired from a heavy steel cannon resting on the floor at the face of the entry and pointing outward, its mouth being about $3\frac{1}{2}$ to 4 feet from the face of the entry. The bore hole of the cannon is $2\frac{1}{4}$ inches in diameter in front and about 3 inches at

the back, the total depth being 21 inches. A charge of 4 pounds of FFF black powder is made up in paper cartridges consisting of two or three ply of newspaper. Three electric, black-powder igniters are used, two in the first cartridge to be placed in the hole and one in the second. The cartridges are slit as they are charged in the hole and each cartridge is pressed back firmly with a wooden tamping bar. Three pounds of clay stemming, just damp enough to pack, is inserted in the hole in four or five lots. The first lot is tamped by hand, but the later ones are sledged heavily into position, making a firm, hard stemming.

2. A platform of six 2-inch planks, each 8 inches wide and 16 feet long, is placed on the floor immediately in front of the cannon, and 25 pounds of the dust is distributed on it. In pure coal-dust tests the dust was distributed at the rate of 2 pounds per linear foot of entry in the 50-foot initiating zone. In the mixed-dust tests, when plenty of dust is available, the loading is usually so increased that the amount of coal dust present is still 2 pounds per foot, except that the total loading in any test must not exceed 5 pounds per foot. About one-half of the dust is distributed on the smooth concrete floor and the balance is placed on the side shelves along the entry.

3. The dust distribution outby the initiating zone was at the rate of 2 pounds of coal dust per linear foot of entry. This amount was also used in tests with mixtures of coal dust and shale dust, except that the total did not exceed 5 pounds per foot. This standard loading was reduced to 1 pound of coal dust^{23b} in test 354 and in subsequent tests, one-third being placed on the cross shelves, one-third on the side shelves and ribs, and one-third on the floor. However, not more than 1 pound of mixed dust per linear foot of entry was placed on the cross shelves and not more than $1\frac{1}{2}$ pounds of mixed dust on the side shelves, the balance being scattered on the floor.

4. Two or more samples of the dust are taken from the shelves before the explosion for screen tests and for chemical analyses, in order to check the percentages of the constituents in the dust mixtures. Moreover, road dust and coke samples are frequently taken after the explosion to determine its effect on the composition of the dust.

TESTS WITH SINGLE-ENTRY ZONES.

The increase in flame velocity and in pressure as an explosion proceeds through a zone of pure coal dust will be shown in a number of tests of different zone lengths.

RESULTS OF THE TESTS.

Table 3 following gives data on five tests in which the explosion was originated by firing a blown-out shot into a 600-foot zone of pure Pittsburgh coal dust, there being no dust in the 1,250 cut-

^{23b} Experience had shown that 1 pound of coal dust in the mixture was sufficient for maximum results.

through except in test 83. These tests were made before the standardizing conditions reached their final development, and the results are not entirely consistent. They give an idea, however, of the velocities and pressures developed at different points.

TABLE 3.—*Results of tests with pulverized Pittsburgh coal dust in 600-foot single-entry zones.*

[Point of origin, station E 1300. Igniting shot, standard blown-out shot, 4 pounds FFF black blasting powder in cannon on floor. Dust zone, station E 1300 to station E 700. Loading 2 pounds per foot with 50 pounds additional on bench in front of cannon; total loading, 1,250 pounds.]

Item.	Test 55. ^a	Test 65. ^a	Test 66. ^a	Test 67. ^a	Test 83. ^b
Date.....	Dec. 2, 1913.	Dec. 29, 1913.	Jan. 2, 1914.	Jan. 6, 1914.	Feb. 6, 1914.
Maximum pressures, pounds per square inch:					
Station E 1150.....	14	-----	13	13	20
Station E 950.....	31	19	16	14	27
Station E 750.....	72	65	63	51	58
Station E 550.....	16	19	35	19	9
Time of tin-foil rupture at stations and velocity of flame between stations:					
E 1150 foil, seconds.....	0.711	1.048	1.061	0.338	0.710
Velocity between E 1150 and E 950, feet per second.....	966	758	609	457	1,112
E 950 foil, seconds.....	.914	1.312	1.389	1.371	.890
Velocity between E 950 and E 750, feet per second.....	6,390	2,963	2,755	1,650	4,350
E 750 foil, seconds.....	.945	1.379	1.462	1.492	.936
Velocity between E 750 and E 550, feet per second.....	2,279	-----	2,317	-----	2,174
E 550 foil, seconds.....	1.083	-----	1.548	-----	1.028

^a Violent explosion was obtained.

^b Violent explosion was obtained. In this test an additional 100 pounds of coal dust was placed in the cut-through.

^c This extraordinary velocity record may be too high through possible retarding of foil at station E950; note corresponding times and velocities of test 83.

DETAILS OF THE TESTS AND DISCUSSION OF RESULTS.

DISTRIBUTION OF COAL DUST.

In all of these tests the coal dust was distributed on side shelves at the rate of 2 pounds per linear foot of entry. As the cross section of the entry averages about 60 square feet, a distribution of 2 pounds per linear foot is equivalent to 0.533 ounce per cubic foot of space. Theoretically, the amount of Pittsburgh coal dust necessary to completely consume the oxygen in a cubic foot of air is 0.123 ounce, so the above distribution is more than four times the theoretical amount; however, as the pressure at Station E750 averaged 62 pounds gage pressure, or five atmospheres absolute, there would be a deficiency at this point, and excess at the start of the explosion. As the dust loading extended only to Station E700, the deficiency or absence of coal dust outby that station accounts for the sudden drop in pressures recorded at Station E550. Near the origin of the explosion only one-fourth to one-third of the dust is swept off the shelves, whereas beyond the first 100 or 200 feet practically all of the dust disappears from the shelves.

SIZE AND ANALYSES OF DUST USED IN THESE TESTS.

The following is an average screen test of the dust used in these tests: 99 per cent through a 100-mesh sieve, 88 per cent through a 200-mesh sieve, 79 per cent through a 240-mesh sieve.

The fineness of the coal as used in these tests exceeds that of dust samples collected in mines working the Pittsburgh bed. However, although the percentage of fine material is greater, it is believed that the amount of 100 and 200 mesh dust per foot of entry does not greatly exceed that present in some mines under the most unfavorable conditions encountered. It is desirable, moreover, that the explosion tests be made under more severe conditions than those encountered in mines, so that the preventive measures tested would surely take care of any explosion that might occur in an operating mine.

The following analysis is an average of the analyses of samples taken from the dusts used in the five tests. The analyses are quite uniform, except that for test 67 the ash was high, being 10.95.

Average composition of dust used in the five tests.

	Per cent.
Moisture.....	2. 32
Volatile matter.....	35. 29
Fixed carbon.....	53. 63
Ash.....	8. 76
Ash and moisture free:	
Volatile matter.....	39. 69
Fixed carbon.....	60. 31

VELOCITIES.

The tin-foil at station E 1150 was fused at times ranging from 0.71 to 1.07 seconds after the igniting shot was fired. The average velocity of flame, as indicated by the melting of the tin-foils (see fig. 12) between points 150 and 550 feet from the origin, was 1,146 feet per second, the minimum rate being 722 feet and the maximum 1,770 feet per second. The minimum velocity of flame between points 350 and 550 feet from the origin was 1,650 feet and the maximum 6,390 feet per second. The velocities for the last 100 feet, as interpolated from the curves, varied from 2,500 to 6,667 feet per second. The results showing velocities in excess of 3,500 to 4,000 feet are questionable, because they may be due to a slight lag in the melting of the inby foils or to the rupture of the outby foils by movements set up by the explosion ahead of the flame.

PRESSURES.

Pressure records in the different tests varied considerably. The highest pressure recorded at the outermost station, 550 feet from the origin, was 71 pounds in test 55.

The range of the maximum pressures in the five tests at the different stations was as follows:

<i>Range of maximum pressures.</i>		
	Pressure limits.	Average.
Station E 1150, 150 feet from shot.....pounds..	13-20	15
Station E 950, 350 feet from shot.....do.....	14-31	21
Station E 750, 550 feet from shot.....do.....	51-72	62

The maximum pressure recorded at a point does not necessarily show the maximum pressure developed at that point at the time of flame passage, because the maximum pressure at a station is often-times recorded later than the time when the flame passed the station. This fact is due to a pressure wave traveling back from some point of higher pressure subsequently developed to a region of lower pressure toward the origin of the explosion. Such a return pressure wave

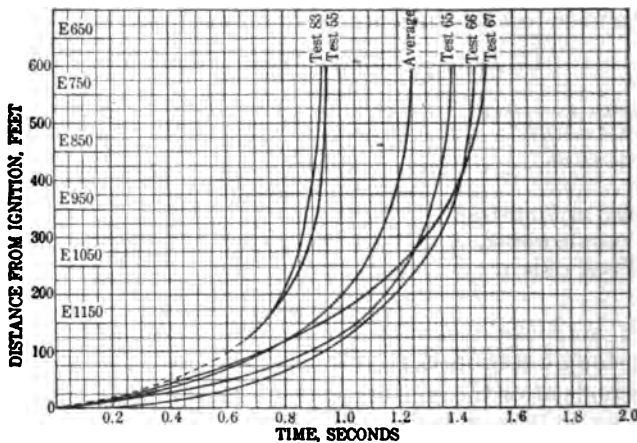


FIGURE 12.—Flame-velocity curves for explosion in 600-foot single-entry zones of Pittsburgh coal dust.

is termed a retonation wave, as defined on a previous page, and is responsible for many odd phenomena, which will be discussed at another place.

SINGLE-ENTRY TESTS WITH DUST ZONES LONGER THAN 600 FEET.

In tests 42 and 46 longer coal-dust zones were arranged than in tests previously described, and higher pressures were obtained at the end of the zones (see fig. 13). The data of the tests follow:

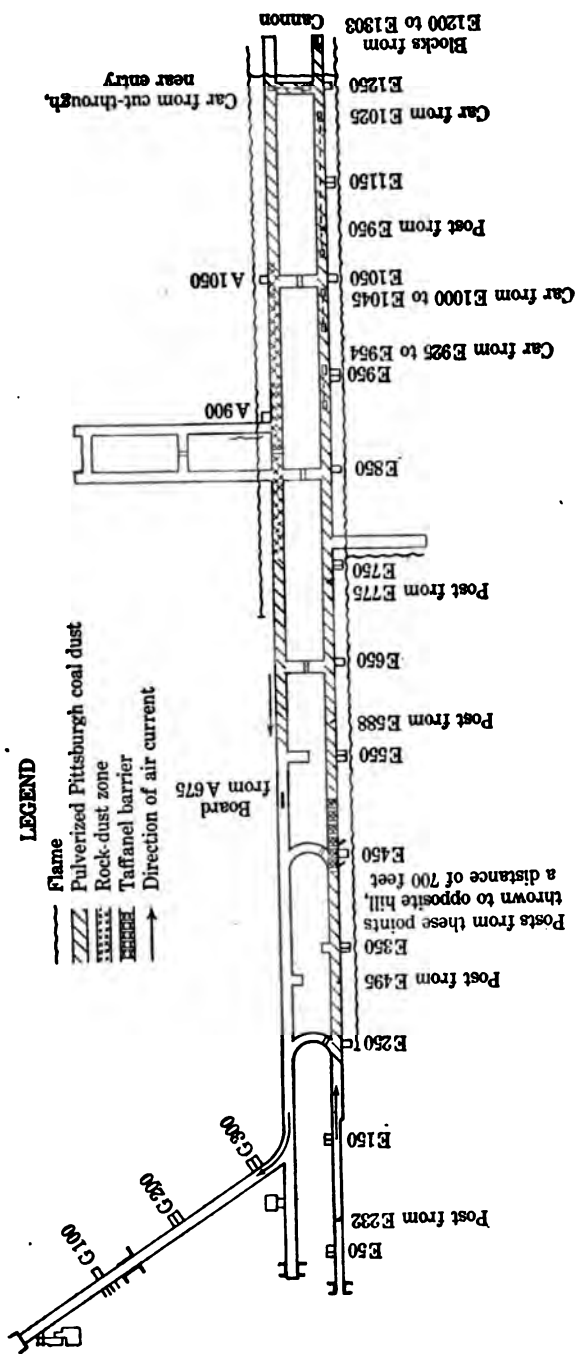


FIGURE 13.—Diagram showing condition of mine as prepared for test 46 and primary results of the explosion. Test made September 23, 1913.

Data in explosion tests 42 and 46.

Item.	Test 42.	Test 46.
Originating shots.....	Cannon at station E 1300 and in 1250 cut-through.	Cannon at station E 1300 and in 1250 cut-through.
Amount of charge.....	4 pounds FFF black powder	4 pounds FFF black powder.
Coal-dust zone.....	<i>Pounds.</i> Stations E 1300 to E 500, 800 feet. 1,000 1250 cut-through..... 100 2 platforms..... 100 Total..... 1,800	<i>Pounds.</i> Stations E 1300 to E 500, 800 feet. 1,000 1250 cut-through..... 100 Stations A 1250 to A 1050, 200 feet. 400 2 platforms..... 100 Total..... 2,500
Obstructions.....	Loaded car at 1250 cut-through, stations E 1075, E 1000, E 950, and in mouth of right butt.	Loaded car at 1250 cut-through, Stations E 1075, E 1000, and E 925.
Time of flame passage..	<i>Station. Seconds.</i> E 1150..... 0.615 E 1050..... .689 E 950..... .792 E 850..... .821 E 750..... E 550.....	<i>Station. Seconds.</i> E 1150..... E 1050..... E 950..... 1.991 E 850..... E 750..... 2.000 E 550..... 2.210
Maximum pressures....	<i>Lbs. per sq. in.</i> E 950..... 19 E 750..... 57 E 550..... 84 E 150.....	<i>Lbs. per sq. in.</i> E 950..... E 750..... 54 E 550..... 119 E 150..... 12
Barriers.....	None.	10-shelf Taffanel barrier, loaded with shale, at stations E 500 to E 440.
Location of cars after explosion.	Car in mouth of right butt turned half around. Car at station E 950 moved inby to station E 1075. Car at station E 1000 moved inby to station E 1300. Car at station E 1075 moved inby to station E 1300. Car in cut-through moved to station A 1250.	Car at station E 925 moved inby to station E 954. Car at station E 1000 moved inby to station E 1045. Car at station E 1075 moved inby to station E 1222. Car in cut-through moved to station A 1250.

* Fusing of foil probably lagged.

The maximum pressures at station E 550 in each of the two tests were registered almost at the beginning of the records, indicating a very rapid rise. The velocities of the flame in the early part of the explosions were quite different; in test 42 a record was obtained at station E 950, 0.792 second after the igniting shots were fired, but in test 46 it required 1.991 seconds for the flame to reach the same point. From this point outby the flames in the respective tests traveled at very high velocity, 2,000 feet and 1,800 feet per second, respectively, and the pressures resulting were great. Figure 14 shows, for test 46, the curves of the tin-foil records and of the pressure records at stations E 750, E 550, and E 150. The distance from the origin is plotted as the ordinates, and the time is plotted as abscissas. The origin of the explosion, arrangement of coal-dust zones, and limiting zones and barriers are shown by the diagram at the left. The pressure curves are plotted as if they had been in the third dimension, perpendicular to the plane of the paper at the proper position, and then revolved through 90° toward the top of the sheet.

EFFECT OF OBSTRUCTIONS ON ADVANCE OF EXPLOSION.

It is believed that the presence of cars in the main entry retards the development of the explosion, as they tend to hold back the explosion wave and the advance air waves that stir up the dust. However, it has been observed in studying the effects of explosion disasters in mines that an explosion after it is well started often develops unusual violence in the vicinity of obstacles. This effect may be due to eddy currents being set up, which assist in forming

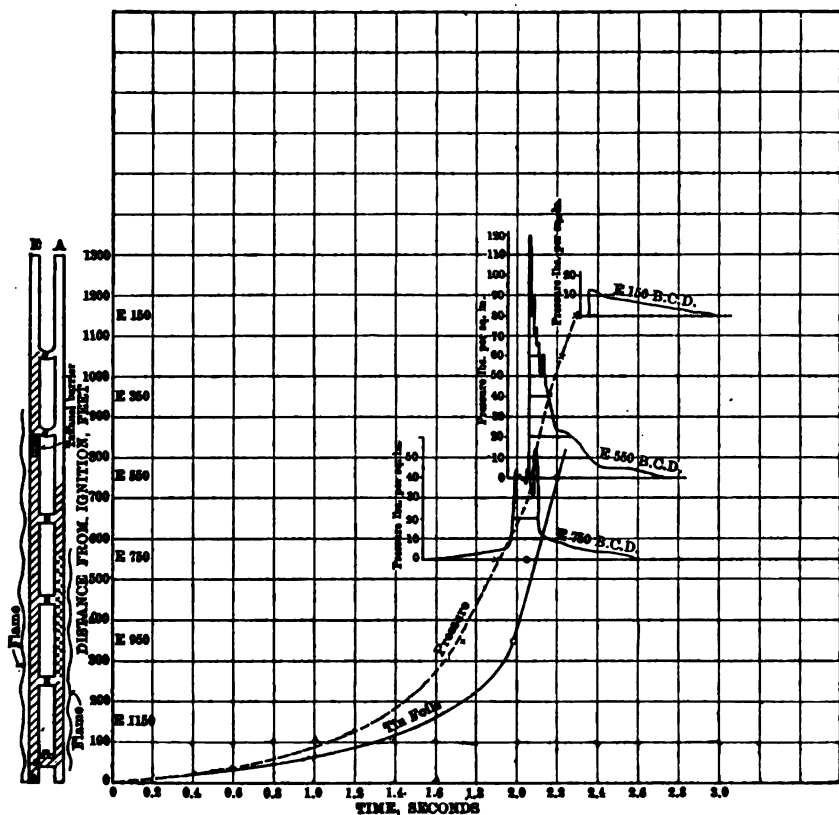


FIGURE 14.—Curves showing results of test 46. Made September 23, 1913.

a dense dust cloud. Results of certain tests at the experimental mine, in which a mine car and no dust was placed in the last cut-through, indicated that the presence of the car aided the development of the explosion, probably because it opposed the release of pressure through this opening and so maintained the propulsive pressure in the main entry.

The position of the cars in the main entry after the explosion is of interest. In test 42 cars at stations E 1000 and E 1075 were thrown to the face of the entry. After both tests, it will be noted, all the cars in the main entry were found in by their previous positions. This result is an example of the movements due to the retonation

waves. In these tests, as the explosion advanced through the zone of coal dust its pressures were comparatively light, and possibly it passed the cars without moving them outby. However, as the explosion traveled beyond the original position of the outby cars the pressure increased rapidly, rising in these tests to 84 and 119 pounds, respectively. Movement in both directions from a point of maximum pressure toward regions of lower pressure took place, the wave that returned toward the origin being the "retonation" wave.

EFFECT OF TAFFANEL BARRIER.

In test 46, a Taffanel barrier of 10 shelves loaded with shale dust was installed at the end of the main coal-dust zone. An auxiliary coal-dust zone of 200 feet was prepared outby the barrier to test its efficiency in stopping the explosion. The barrier operated successfully and the pressure decreased from 119 pounds at station E 550 to 12 pounds at station E 150.

TESTS WITH DOUBLE-ENTRY ZONES.

Five test with pure Pittsburgh coal dust were made in which both entries had coal dust distributed in them. The usual rate of distribution, 2 pounds per linear foot of entry, equivalent to 0.533 ounce per cubic foot of space, was adhered to. Tests 108 to 115 were witnessed by J. Taffanel, director of the French mine experiment station and coal-dust gallery at Liévin, Pas de Calais, France—a station that was destroyed in the World War. In the three tests (Nos. 105, 109, and 113) the dust was distributed on side shelves, in test 115 on cross shelves only, and in test 138 on cross shelves and side shelves (see Table 4).

In these tests very fine dust was used on the platform in front of the cannon. This dust was collected from the bags of the finest float dust taken from the air-discharge pipe of the cyclone collector of the pulverizing plant. It has a brownish appearance, but has practically the same composition as the standard pulverized dust used throughout the remainder of the zone. The screen tests of the two dusts were as follows:

Results of screen tests of dusts.

		Brownish float dust (used on platform).	Pulverized dust (used throughout zone).
Through 100-mesh.....	per cent..	100.0	99.7
Through 200-mesh.....	do....	98.8	93.3
Through 240-mesh.....	do....	96.4	88.5

The proximate analysis of the pulverized dust used in the test zone is as follows:

Proximate analysis of the pulverized dust.

	Per cent.
Moisture.....	2.32
Volatile matter.....	36.03
Fixed carbon.....	54.67
Ash.....	7.02

TABLE 4.—Results of tests with pure Pittsburgh coal dust in double-entry zones.

Test No.	Origin.	Coal-dust zone.		Instrument records in entry or air course.	Maximum pressure.			Time of tin-foil rupture at stations, and flame velocities between stations.												
		Locality in mine.	Length.		Station 1180.	Station 960.	Station 750.	Foil at station 1250.	Veloc-ity.	Foil at station 1150.	Veloc-ity.	Foil at station 1050.	Veloc-ity.	Foil at station 950.	Veloc-ity.	Foil at station 850.	Veloc-ity.	Foil at station 750.		
105	Station E 1300.	Stations E 1300 to E 800. 1250 cut-through. Stations A 1250 to A 800.	Feet.	Entry.....	Lbs. per sq. in. 34	Lbs. per sq. in. 29	Lbs. per sq. in. 10	Sec-onds.	Feet per second.	Sec-onds.	Feet per second.	Sec-onds.	Feet per second.	Sec-onds.	Feet per second.	Sec-onds.	Feet per second.	Sec-onds.		
			500 50 450	Air course.	31	19	.....	.....	.....	.....	1,136	0.682	1,075	0.770	2,175	0.855	1,850	0.909	883	1.021
109	Station 1250 offset.	Offset and cut through. Stations E 1250 to E 800. Stations A 1250 to A 950.	70 450 300	Entry.....	13	21	7	0.613	334	.....	.....	.....	394	1.176	1,252	1.244	662	1.306	50	3.300
			.....	Air course.	18	14	.....	.....	.....	.....	.....	.....	.....	.....	541	1.080	694	1.204	.....	.....
113	Station E 1300.	Stations E 1300 to E 800. 1250 cut-through. Stations A 1250 to A 950.	500 50 300	Entry.....	24	30	13	.527	375	.794	.704	.944	667	1,450	1.013	.....	1.014	.....	.....	
				Air course.	18	32	9									870	.942	862	.958	
115	Station 1250 offset.	Offset and cut through. Stations E 1250 to E 950. Station A 1250 to A 950.	70 300 300	Entry.....	54	37	36	.740	.....	.734	.....	.....	.....	.....	.....	1,675	.913	3,250	0.944	
			.....	Air course.	24	61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
138	Station 1250 offset.	Offset and cut through. Stations E 1250 to E 950. Stations A 1250 to A 950.	70 300 300	Entry.....	43	63	10	.390	575	.564	.564	.713	1,470	.781	.....	.....	.....	.....	.....	
			.....	Air course.	40	80	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

a Dates of tests, 1914: 105, Apr. 18; 109, Apr. 29; 112, May 9; 115, May 30; 138, July 10.

b Velocity record too high, probably owing to momentary delay in fusing of foil at A 1180.

As in the previous tests considered, the maximum pressures at the stations nearer the origin in these fast-moving explosions did not occur at the time of flame passage. The plotting of the maximum pressures would give a wrong idea, therefore, of the development of the explosions. It is necessary to consult the charts of the different tests to determine the pressures that should be taken for this purpose.

The instrument-record sheet for test 105 (see fig. 10, p. 74) and other double-entry tests is plotted a little differently from that for single-zone tests. The distances along the entry are plotted upward toward the top of the sheet, whereas those along the cut-through and air course are plotted downward (see p. 73). The pressure curves are as if they had been plotted in planes perpendicular to that of the paper and then revolved toward the upper side of sheet. The heavy black marks shown at the base of the pressure curves for stations E 1150 and A 1150 represent the time of flame photographs. The record of an air-motion device is plotted at station E 750. When the record is on upper side of the E 750 base line, it denotes outward movement of the gases, whereas an inward movement would be plotted below the E 750 line. A shock-wave of 8 pounds was recorded at station E 1150, followed, after the usual pressure drop, by a gradually increasing pressure, reaching 10 pounds at the time (0.6 seconds) of the passage of the flame. The pressure then continues to rise regularly, as the pressure farther outby rises, when—as in this test—the explosion is increasing in violence as it progresses. Similar pressure changes are recorded by the air-course manometer at A 1150. Comparison of the flame photographs obtained by the French manometers with the curves for the tin-foil indicators shows that the manometer records the flame somewhat earlier than the tin foils. This may be either because the first flame photographed by the manometer may be a spear point in the middle of the entry, whereas at the time of melting the foil the flame probably fills the entire cross section, or because a short time elapses after the arrival of the flame before the foil fuses and breaks the circuit. The same situation is even more strikingly shown by the records of E 1150 in test 109 (fig. 15) and of A 1150 in test 115 (fig. 11).

It is interesting to note that the maximum pressures in this explosion were recorded at all stations at about the same time, an unusual occurrence, the reason for which is not evident but may be due to the difference in instruments, in this group of tests the B. C. D. manometers being used at the stations other than E 1150 and A 1150. These manometers were later discarded because of having greater inertia than the French type. Depressions below the atmospheric line were recorded by both French manometers, the latter part of the curves showing suction over the interval 3.6 to 7.8 seconds, or for a

period of 4.2 seconds. The suction at station E 1150 was almost 5 pounds and that at station A 1150 about 3 pounds.

Test 109 (fig. 15) was originated by a shot fired from a cannon at the face of a small stub 25 feet long driven into the north rib of the 1,250 cut-through, the stub being parallel with and midway between the main entry and the air course. The purpose of this arrangement

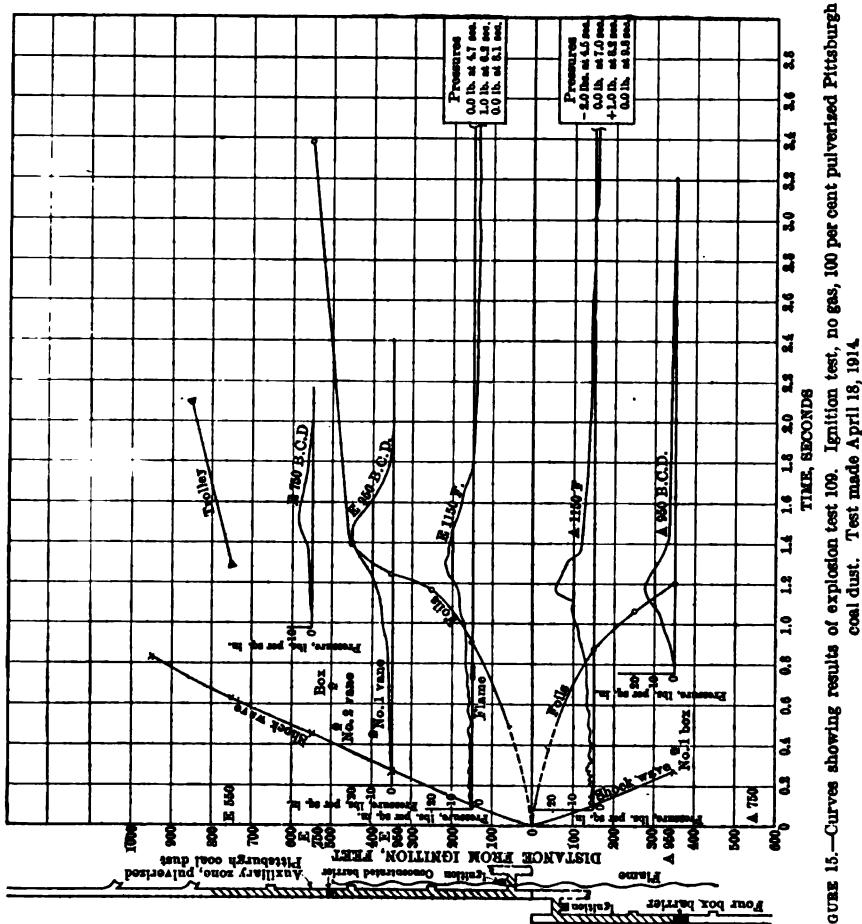


FIGURE 15.—Curves showing results of explosion test 109. Ignition test, no gas, 100 per cent pulverized Pittsburgh coal dust. Test made April 18, 1914.

was to try the effect of employing in the starting point of an explosion symmetrical conditions with reference to its separate branches in the main entry and air course. Coal dust was distributed on a platform on the floor in the stub and on side shelves through the test zones in the cut-through and both entries.

A double shock-wave record was obtained in both entries, the second record in each case being due to reflection of the shock wave

from the face of the respective entries. At station E 1150, and likewise at station A 1150, there was a relatively long period of suction, succeeded by a second period of positive pressure; at the latter station this second period of positive pressure was succeeded by a second period of negative pressure. Reversal in the direction of movement of the afterdamp gases are found to correspond with the

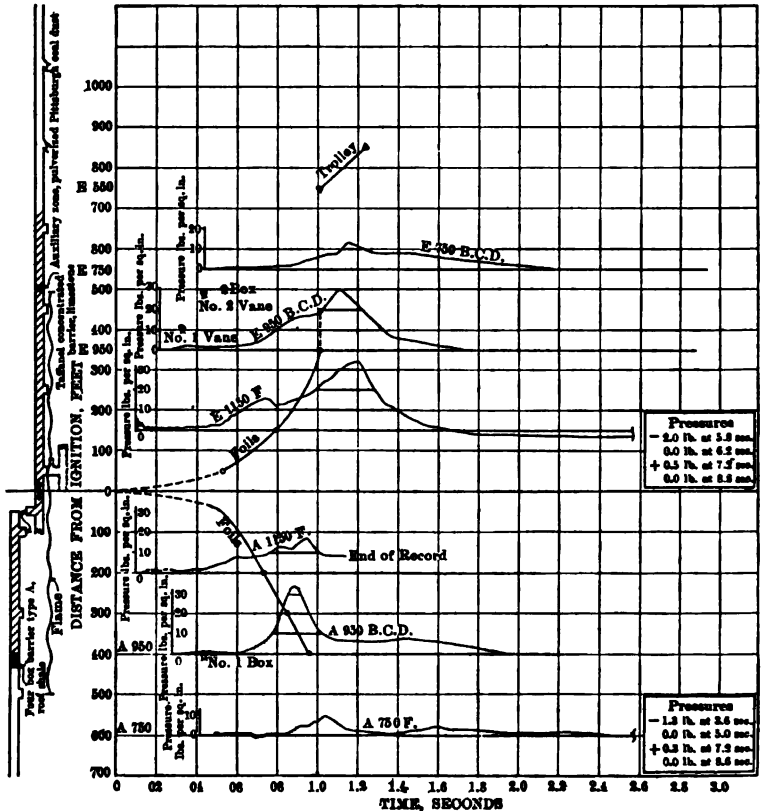


FIGURE 16.—Curves showing results of test 113. Ignition test, no gas, 100 per cent pulverized Pittsburgh coal dust. Test made April 29, 1914.

alternations of positive and negative pressures. In some tests it is possible for observers at the surface to count as many as ten reversals of the air current at the main opening after the principal explosion wave has appeared.

In test 113 (see fig. 16) the origin of the explosion was at station E 1300, the conditions being similar to those of test 105, except that the air-course explosion zone was only 300 feet long. The results are shown in figure 16.

The pressure development in the main entry is very similar to that of test 105, but the flame velocities are lower. The explosion in the main entry was terminated by a Taffanel concentrated barrier at station E 800. The maximum-pressure peak at station E 750 was therefore the result of a direct-pressure wave from the explosion inby; the peak at station E 1150 occurred after that at station E 950 and was partly caused by a retonation wave. Similarly, in the air course, the peak at station A 1150 occurred after that at station A 950, and was partly due to a retonation wave from the latter point. These effects of the retonation waves are better shown in the manometric records of later tests in which the French or bureau manometers were used.

In test 115 (see fig. 11, p. 75) all of the coal dust was placed on cross shelves just beneath the entry roof. The results indicate that this is the most effective position for placing coal dust in the entry to assist the development of an explosion. In this test the developments of the separate branches of the explosion traversing the main entry and the air course are approximately the same. The type A, rock-dust, box barriers used in this test did not successfully stop the explosion, so that high pressures were obtained outby station 950, but the large depression in the pressure curve immediately after the peaks indicate some checking action outby, the usual retonation-wave effect in sustaining or building up the pressure being absent.

Test 138 was the last of the series with pure Pittsburgh coal dust in this length of zone. The explosion (see fig. 17) was the most violent of all tests made for the respective zone length. The dust was distributed on both side and cross shelves; therefore the area exposed from which dust could be raised was larger than in previous explosions. The explosion branches were terminated by door barriers; therefore no air was moving in the explosion zone at the time of starting the explosion. The velocity of the flame from the origin to station E 950 was the fastest recorded for a pure dust test over the full length of zone. The maximum pressure at station A 950 (86 pounds) is the highest recorded at this point in any test. The door barriers operated successfully. In this test, as in tests 109 and 115, the cannon was in the stub off the last crosscut. It was anticipated, as the igniting shot was directed squarely against a rib only 25 feet distant, that there would be a slowing up of the initiation of an explosion. This conclusion seemed to be indicated by test 109, but test 138 disproved it.

TESTS WITH DUSTLESS ZONES.

Four tests were made with "dustless" zones, 500 to 1,000 feet long, outby short initiating zones of Pittsburgh coal dust. The results of this series, made in midwinter when the mine was very dry, are instructive as indicating the ineffectiveness of any method for preventing coal-dust explosions that would depend entirely on cleaning up the dust. In the so-called "dustless" zones of this series the surfaces were cleaned by using whisk brooms and house brooms, then

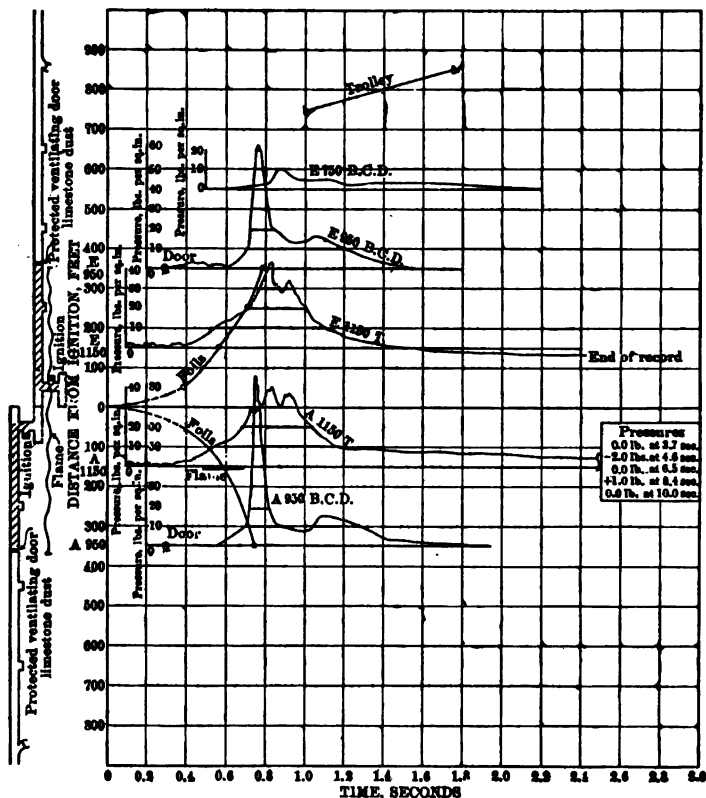


FIGURE 17.—Curves showing results of test 188. Ignition test, no gas, 100 per cent pulverized Pittsburgh coal dust, July 10, 1914.

by blowing with compressed-air jets, the dust being carried in advance of the cleaners by a strong ventilating current. These tests were made before the surfaces in the inner part of the mine had been "gunited." Even with this method of cleaning there was a slight amount of dust visible on close inspection of the surfaces at some points. However, as the floor was of damp clay well packed, it is believed that the zone was cleaner than could be obtained in an operating mine after the most thorough cleaning possible. The

results are summarized in Table 5. These tests were made before the surfaces in the inner part of the mine had been "gunited" and the floor concreted, thus permitting removal of practically all dust. The conditions surrounding the tests were those that would be found in a commercial mine where every care had been taken to remove the dust.

In test 82 the usual standard blown-out shot was fired into a coal-dust zone 100 feet long with a 500-foot dustless zone outby. The flame as indicated by safety matches extended to station E 1050; that is, 250 feet from the igniting shot, or 150 feet into the "dustless" zone.

In test 81 the conditions were the same except that the 1250 cut-through was loaded with an additional 100 pounds of fine dust. Close examination of the surfaces between stations E 1200 and E 700 indicated that there was a little dust behind the rib posts and on the floor along the rib. In this test the flame passed through the dustless zone to station E 425, 875 feet from the origin and 775 feet beyond the coal-dust zone.

In test 80 a zone 200 feet long was prepared in the main entry and 100 pounds of coal dust was distributed in the 1250 cut-through. The main entry from station E 1100 to station E 350 had been cleaned in the usual way with brooms and compressed air, but the outby part between stations E 700 and E 350 was not as clean as the part inby. The explosion developed strongly and the flame extended throughout the entire length of the main entry and into the open air.

In test 79 a 300-foot zone was prepared with coal dust distributed in the cut-through, as usual, and the dustless zone was 1,000 feet long, the main entry from E 1200 to E 200 having been cleaned. The flame, as in test 80, extended the full length of the main entry.

The results of this series indicate unquestionably the necessity for supplementing the removal of coal dust by some method, such as wetting or rock dusting, that will render inert the coal dust unavoidably left in the mine. The use of rock dust will not only prevent clouds of pure coal dust forming in the treated zones, but will also furnish a means of limiting any explosion that may be started in an untreated part of the mine.

TABLE 5.—Results of short-zone tests with dustless zones outby.

[Dustless zone was cleaned by compressed air jets, the dust being carried forward in strong ventilating current.]

Test No.	Date.	Origin.	Coal-dust zone.	Quantity of coal dust.	Dustless zone.	Barriers.	Maximum pressure.				Time of tin-foil rupture at stations and flame velocities between stations.						Length of flame as indicated by gun-cotton tufts.	
							Station E 1150.	Station E 950.	Station E 750.	Station E 550.	Fall at station E 1150.	Fall at station E 950.	Fall at station E 750.	Fall at station E 550.	Fall at station E 350.			
82	Feb. 5 1913.	Station E 1300.	Between stations E 1300 and E 1200 (100 feet). Platform.....	Lbs. 200	Between stations E 1200 and E 700.	10 Taffanel shelves, E 700 to E 640 and A 1100 to A 1040.	Lbs. per sq. ft. in.	Lbs. per sq. ft. in.	Lbs. per sq. ft. in.	Lbs. per sq. ft. in.	Ft. per sec. onds.	Ft. per sec. onds.	Ft. per sec. onds.	Ft. per sec. onds.	Ft. per sec. onds.	Reached stations E 1050 and A 1125, 150 feet in dustless zone.		
				50														
				250														
81	Feb. 4	do.	Between stations E 1300 and E 1200 (100 feet). 120-out-through Platform.....	200	Between stations E 1200 and E 700; little dust behind rib posts and on floor.	10 Taffanel shelves, E 700 to E 640 and A 1100 to A 1040.	12	7	7	3	0.894	235	1.365	220	3.185	Reached stations E 432 and A 975 through dustless zone.		
				350														
				400														
80	Feb. 3	do.	Between stations E 1300 and E 1100 (200 feet). Cut-through... Platform.....	400	Between stations E 1100 and E 850; little dust on ribs.	None in entry; 7 Taffanel shelves, A 1100 to 1082.	19	20	38	46	.634	.....	.639	629	0.947	Reached stations E 0 and A 775 through dustless zone.		
				100														
				50														

[illegible]

Average analysis of dust used:

Moisture.....	2.12
Volatile matter.....	35.88
Fixed carbon.....	53.63
Ash.....	8.37

Average screen test of dust used:
99.9 per cent through 100-mesh.
93.4 per cent through 200-mesh.
86 per cent through 240-mesh.

MINIMUM QUANTITY OF COAL DUST FOR PROPAGATION.

After the surfaces of the inner part of the experimental mine had been lined with cement and concrete they could be cleaned much more thoroughly than before. It was thought possible, therefore, to obtain more definite information regarding the minimum quantity of coal dust that would propagate an explosion. Previous tests had been made with cleaned or so-called "dustless" zones, but apparently the rough surfaces of the coal and roadbed had retained sufficient dust to assist in propagating or even to propagate an explosion. Four such tests were made. In two of them the coal dust was placed on special shelves of 1-inch boards placed across the entry and resting loosely on the side shelves, which served as brackets, about 3 feet from the floor; in the other two tests the dust was placed on the regular fixed shelves near the roof. In all four of these tests the standard starting impulse was employed; that is, firing a 4-pound charge of FFF black powder into a 50-foot ignition zone of pulverized Pittsburgh coal dust. The accompanying table gives the more important data of the tests:

Data on the four tests.

Test No.	Dust distribution.		Propagation obtained.	Pressure (pounds per square inch).				Remarks.
	Pounds per linear foot.	Ounces per cubic foot.		E 1150.	A 1150.	E 950.	A 950.	
262	0.3	0.06	Yes....	30	31	42	28	Special shelves.
305	.12	.032	No.....	1	1	1	1	Do.
290	.3	.08	Yes....	9	4	10	10	Regular cross shelves and side shelves.
296	.15	.04	No.....	4	2	1	1	Do.

Comparison of tests 262 and 290 indicates that the special shelf arrangement was more favorable to propagation than the regular arrangement; this fact was due either to dust being placed midway between the roof and floor of the entry, or to the overturning of shelves, or to both features combined.

These tests are of unusual interest in comparison with those made under artificial conditions in surface galleries. Taffanel in small gallery tests in 1907 had one propagation in three trials with as little as 0.23 ounce per cubic foot (23 grams per cubic meter) but required 0.07 ounce per cubic foot to produce propagation regularly. At the Pittsburgh 6½-foot diameter gallery in 1909, Rice obtained propagation in two tests, with 0.032 ounce per cubic foot.

The French gallery was but 25 feet long; only 40 feet of the Pittsburgh gallery was used, so the immediate influence of the respective igniting shots was great. Propagation with these small amounts through long distances in mine passages therefore might not have

happened. In the experimental mine test 295 with 0.04 ounce, and test 305 with 0.032 ounce did fail to propagate more than 200 feet, but tests 262 and 290 with loading of 0.08 ounce, propagated; the former with special light loading shelves—the throwing down of which insured that all the coal dust would be put in suspension—was very fast and violent. Pressure and flame velocity curves for test 262 are shown in figure 59, and interesting retonation wave phenomena are discussed on page 64. The loading of 0.3 pound per linear foot or 0.08 ounce per cubic foot of space if distributed over the walls, roof, and floor of the entry would make a film only 0.0025 of an inch thick, or about eight-tenths of the thickness of a leaf of this book. Such a film is imperceptible to the eye in an unlined mine entry.

The violence of the explosion in test 262 and the incomplete propagation in test 295, with a loading of 0.04 ounce per cubic foot of air space and without the light cross-shelves used in test 262, indicates that the minimum limit of quantity of dust like the Pittsburgh dust required for propagation closely approaches 0.04 ounce per cubic foot, or 40 grams per cubic meter, and a dust of lower ash and higher volatile-combustible content might show a still lower limit.

TESTS WITH SUPERDUSTING NEAR ORIGIN.

In the winter of 1912-13 difficulty was experienced in procuring duplicate results from tests with similar dust distribution. In making changes for the purpose of obtaining more consistent results it was suggested that the placing of cross shelves with coal dust on them in the first 50 feet might assist in the production of a dense preliminary dust cloud and thus aid the explosions in getting a rapid start.

In test 62, therefore, 10 cross shelves of 1-inch boards 10 inches wide were placed across the entry at 3-foot intervals from station E 1287 to station E 1258, the first one being about 12 feet out by the front of the cannon. The first three shelves were 1 foot 4 inches above the floor, the fourth and fifth 2 feet 6 inches, the sixth and seventh 3 feet 4 inches, and the last three 4 feet 4 inches. The height of the roof is 6 feet 2 inches. When the igniting shot was fired, no explosion resulted. All the shelves but one were thrown down and broken.

Tests 63 and 64 were made under the same conditions and gave the same results. Test 106 was made at a later date with the same arrangement of dust distribution in by 1250, but an explosion resulted. Test 134 was made later and the results confirmed those of tests 62, 63, and 64; that is, no explosion resulted. Table 6 summarizes the results of these tests.

TABLE 6.—Data from tests of Pittsburgh coal dust with superdusting near origin of explosions, station E 1300.

Test No.	Date.	Coal-dust zone.	Quantity of coal dust used (pounds).	Extent of flame as indicated by gun-cotton tufts.		Number of transverse shelves blown down.
				Station.	Distance from origin.	
62	1913. Dec. 27	Between stations E 1250 and E 700.....	1,100	E 1250	c 50	All but one.
		Between stations E 1250 and E 1283, on side shelves.	25			
		Between stations E 1287 and E 1258, on 10 transverse shelves.	75			
		Platform.....	50			
			1,250			
63	Dec. 27	Between stations E 1250 and E 700, same as in test 62; fresh dust on side and transverse shelves and on platform.	133	E 1250	c 50	Four.
64	Dec. 30	Between stations E 1250 and E 700, same as in test 62. Between stations E 1250 and E 1300, fresh dust on side and transverse shelves and on platform.	150	E 1275	c 25	All but two.
106	1914. Apr. 21	Between stations E 1300 and E 1250, on side shelves.	25	E 1050 A 900	b 250	All but three.
		Between stations E 1287 and E 1258, on transverse shelves.	75			
		Platform.....	50			
		Between stations E 1250 and E 1200.....	100			
		1250 cut-through.....	100			
134	July 2		350	E 1275	c 25	
		Between stations E 1250 and E 1300, on side shelves.	25			
		Between stations E 1287 and E 1258, on transverse shelves.	75			
		Platform.....	50			
		Between stations E 1250 and E 1200.....	100			
			250			

a Non propagation.

b Propagation.

Average coal-dust analysis:

Moisture.....	per cent..	2.02
Volatile matter.....	do.	36.17
Fixed carbon.....	do.	54.09
Ash.....	do.	7.74

Screen test:

99.7 per cent through 100-mesh.
88.6 per cent through 200-mesh.
79 per cent through 240-mesh.

In four out of five tests, therefore, an explosion failed to occur with this method of dust distribution. The accompanying sketch (fig. 18) shows the arrangement of the igniting shot and that of the shelves. It can be seen that the dust on the shelves would be in the path of the flame; the conclusion is that such a dense cloud of dust was made that it blanketed the flame.

The results of the three earlier tests were sent to the foreign coal-dust investigators. Victor Watteyne, of Belgium, and Julian Czapinski, of Austria, reported that tests made by them gave similar results.

Although those tests indicated that an excess of dust blanketed the flame of the shot, it must be noted that the dust was in a very favor-

able position for such action, was very fine, and was close to the shot, so a large amount would be brought into suspension by the blast impinging on the cross shelves. The same amount of dust distributed on side shelves or on the floor does not bring about the same result, as only portions of the dust would be raised by the eddying air currents.

It would be most unwise, therefore, to depend on a great accumulation of coal dust in mines to blanket an explosion, as has been proposed by several persons. The presence of the excessive coal dust accumulations instead of being protection might easily be the cause of a widespread, disastrous explosion.

After a dust explosion is fairly under way the effect of superdusting with coal dust might be as follows: The explosion would be temporarily checked through absorption of heat by the surplus dust raised into the air, resulting in lower pressures and consequently in less violent eddying of the advance air currents; thus less dust would be brought into suspension and the explosion permitted to advance momentarily with less violence while a balance was being established. In other words, the pace of an explosion adjusts itself automatically to the quantity as well as purity of the explosive dust it can feed upon above the maximum quantity needed for propagation, just as a gas explosion will be rapid or slow depending on the proportions of gas and air, and, at the start, whether or not premixed.

EFFECT OF MOISTURE ON ENTRY SURFACES.

In winter the mine surfaces are pretty dry except at certain places where water seeps in, the intaking cold air being rapidly warmed far above the saturation point. In the summer, however, the comparatively

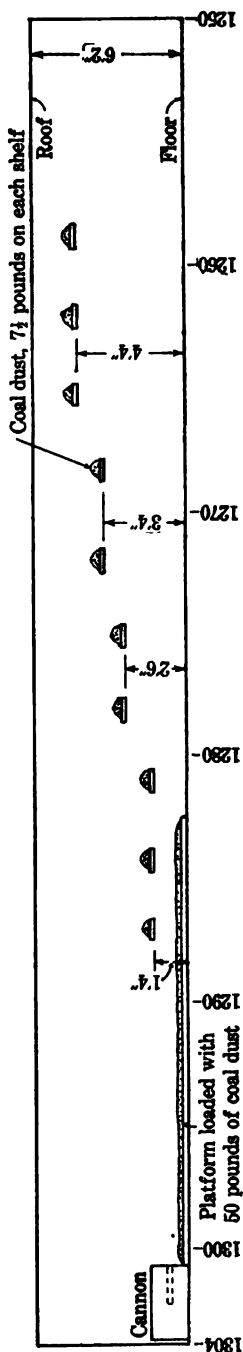


FIGURE 18.—Diagram showing positions of special shelves in tests with superdusting near the origin of the explosion.

short length of air travel in the mine causes the entire mine to become wet through deposition of moisture from the air current, which is cooled below the saturation point as it passes through the mine.

In the summer months, consequently, great difficulty was encountered in making satisfactory tests. Most of the summer of 1913 was taken up in testing various arrangements of ignition conditions to get (1) an ignition of the coal dust, and (2) a development of the explosion similar to that obtained when the mine was dry. It was found possible, after a few tests, to obtain ignition and propagation through a zone of pure coal dust, yet the pressures developed were low. The weakness of the explosions is believed to be due largely to the wet condition of the mine surfaces, although other factors may have contributed their effect.

RESULTS OF THE TESTS.

Table 7 gives data on a number of tests run in summer and on four tests run in winter.

TABLE 7.—Results of similar tests made in summer and in winter, showing the effect of moisture on the entry surfaces
(All tests made with pure pulverized Pittsburgh coal dust, distributed in single-entry zone.)

Test No.	Date.	Ignition conditions.		Dust zone, extent and amount of loading.	Dust-raising shots.		Obstructions, position and character.	Pressure (pounds per square inch).				Remarks.
		Position of igniting shot.	Character of igniting shot.		Position.	Character.		Station E 1150.	Station E 960.	Station E 750.	Station E 550.	
29	1913. July 2	E 1299, cannon 2 feet above rails.	2½ pounds of FFF black powder.	<i>Pounds.</i> E 1300 to E 1000 (2 600 pounds per foot). E 1250 to CT 25 (2 50 pounds per foot). Bench at face..... 50 700	Cut-through, 20 feet from center of entry. E 1245..... E 1200.....	½ stick (2 ounces) Red H No. 6 permissible. .....do..... 1 stick (4 ounces) same.			12	5		Mine wet; dust raisers fired 2 to 3 seconds before cannon; slow explosion
30	July 5	do.....	do.....	E 1300 to E 900 (2 800 pounds per foot). E 1250 to CT 25 (1 50 pound per foot). Bench at face..... Thrown on roof to coat wet surfaces. 100 1000	Cut-through, 20 feet from center of entry. E 1240..... E 1200.....	½ stick (2 ounces) Red H No. 6 permissible. .....do..... 1 stick (4 ounces) same.			27	23		All surfaces swept with brooms; mine fairly dry in to E 550; otherwise damp to wet; cannon fired three sec- onds after dust raisers; slow explosion.
31	July 10	do.....	do.....	E 1300 to E 1000 (2 600 pounds per foot). E 1250 to CT 25 (2 50 pounds per foot). Bench at face..... 50 700	Cut-through, 20 feet from center of entry. E 1245..... E 1200.....	½ stick Minite. .....do..... .....do.....		(c)	(c)	(c)	(c)	Surfaces swept with brooms; some dust noted, but was damp; all surfaces were damp to wet; cannon fired about 2½ seconds after dust raisers; weak explosion.

a Pressures too low to record.

TABLE 7.—Results of similar tests made in summer and in winter, showing the effect of moisture on the entry surfaces—Continued.

Test No.	Date.	Ignition conditions.		Dust zone, extent and amount of loading.		Dust-raising shots.		Obstructions, position and character.	Pressure (pounds per square inch).				Remarks.
		Position of igniting shot.	Character of igniting shot.			Position.	Character.		Station E 1150.	Station E 950.	Station E 760.	Station E 550.	
32	1913. July 18	E 1300, cannon.	2½ pounds of FFF black powder.	E 1300 to E 900 (2 500 pounds per foot). E 1250 to C1 25 (2 50 pounds per foot). Platform at face... 50 Dust rakers..... 60	Pounds. 950	Cut-through, E 1245, E 1200, E 1125.	Each was ½ stick of Minite, placed under platform having 15 pounds of coal dust on it.			0	3		Dirt on surfaces moist enough to be picked by hand; considerable dust on surfaces, but surfaces were wet; weak explosion.
33	July 22	E 1300, cannon; E 1250 cut-through cannon pointing diagonally out and across entry.	2½ pounds of black powder in each cannon.	E 1300 to E 700 (2 1,200 pounds per foot). E 1250 to C1 25 (4 100 pounds per foot). Platform at face... 100 1,400		None.			6	13	21		Surfaces damp and floor dust can easily be added in hand; explosion slow-starting, afterwards becoming strong.
34	July 25	E 1300, cannon; E 1250 cut-through cannon pointing diagonally across and out of entry.	do.	E 1300 to E 700 (2 1,200 pounds per foot). E 1250 to C1 25 (4 100 pounds per foot). Platform at face... 100 1,400		None.		Car at E 900, car at E 800, car at E 1000.	11	13	7		Mine in general was damp, but a little drier than in previous test; air course roof and sides had been swept out to E 1050 previous to explosion, weak explosion.
35	July 29	do.	do.	E 1300 to E 700 (2 1,200 pounds per foot). E 1250 to C1 25 (4 100 pounds per foot). Platform at face... 100 1,400		None.		Car at E 900, loaded; car at E 800, loaded; car at E 1000, loaded.	16	11	6		Roof and sides had been swept clean and floor had been scraped with shovels out to E 450; air course to A 900; surfaces damp to wet; weak explosion.

36	Aug. 1	E 1300, cannon.	24 pounds of F.F.F. black powder.	E 1300 to E 500 (2 1,600 pounds per foot). Platform at face... 50 Platform at E 1250 50 1,700	None.	Car at A 1100, loaded; car at E 1000, loaded; car at E 900, loaded; car at E 800, loaded; car at E 700, loaded.	12	19	Roof and sides swept with brooms from E 400 in to face and A 550 to face; floor scraped to E 1300 and A 850 inby; slate dust on floor between E 0 and E 700 (damp); surfaces wet to damp; violent explosion near mine mouth.
45	Sept. 19	E 1300, cannon; E 1250 cut- through can- non pointing dia g onally across and out of entry.	4 pounds of F.F.F. black powder in each can- non.	E 1300 to E 900 (2 800 pounds per foot). Platform at face... 50 Platform at E 1250 50 900	None.	Car at west end of 1250 cut-through; car at E 1075; car at E 1000; car at E 925.	5 ¹ 3	3	Surfaces swept by brooms; were damp to wet through- out; weak explosion.
55	Dec. 2	E 1300, cannon.	4 pounds of F.F.F. black powder.	E 1300 to E 700 (2 1,200 pounds per foot). Platform at face... 50 1,250	None.	None.	14 31	72 16	Air course dry and dusty; E 640 to face cleaned with compressed air; dry outby E 940 and A 1060; violent explosion.
65	Dec. 29	do.	do.	E 1300 to E 700 (2 b) 200 pounds per foot). Platform at face... 50 1,250	None.	None.	19 65	19	Rather dry, except stations E 1035 to E 1100, and E 980; considerable dust noted both inby and outby coal- dust some used in test 62; violent explosion.
66	1914. Jan. 2	do.	do.	E 1300 to E 700 (2 1,200 pounds per foot). Platform at face... 50 1,250	None.	None.	13 16	63 35	Surfaces E 700 to A 1100 cleaned with compressed air; E 450 to E 945 dry; E 1100 face dry; A 1275 to A 1050 surfaces dry; violent explosion.
83	Jan. 6	do.	do.	E 1300 to E 700 (2 1,200 pounds per foot). E 1250 to A 1250 (2 pounds per foot). Platform at face... 50 1,350	None.	None.	20 27	53 9	E 350 to E 640 surfaces dry; entry was swept and cleaned to E 130; E 700 to A 1100 cleaned with compressed air; E 1115 to A 1025 sur- faces dry; E 700 to E 940, dry; violent explosion.

^b Dust was residue from three previous tests (Dec. 27 to 29) except 100 pounds of fresh dust near face.

DETAILS OF THE TESTS AND DISCUSSION OF RESULTS.

TEST 29.

Test 29 was made with a 300-foot coal-dust zone. The originating shot was fired from the cannon at the face of the main entry, a preliminary dust cloud being made by firing three "dust raisers." One of these was placed in the cut-through 20 feet from the main entry, one at station E 1245, and one at station E 1200, the first two consisting of one-half stick each and the last of a whole stick (4 ounces) of a permissible explosive suspended about the middle of the entry. The dust was distributed on a platform in front of the cannon and on side shelves along the entry. The resulting explosion was slow moving and of low pressure.

TEST 30.

Before test 30 was made the mine surfaces were swept with brooms. This action eliminated most of the larger drops of water, but caused the drier parts of the surface to become rather wet. In addition to the usual dust distribution of 2 pounds per foot and the load on the platform, 100 pounds of dust was thrown on the roof to coat the wet surface. A more violent explosion resulted, but the maximum pressure, 550 feet from the origin, was only 26.6 pounds.

TEST 31.

Test 31 was made under conditions very similar to those of test 30, except that no dust was thrown on the roof. The result was a very weak explosion.

TEST 32.

A slightly different form of dust raiser was used in test 32. Small platforms of 1-inch boards, about 3 feet by 8 feet in size, were placed at a point 20 feet in the last cut-through and at stations E 1245, E 1200, and E 1125. One end of each platform was raised 8 inches from the floor, the explosive being placed beneath it, and 20 pounds of coal dust was spread over the top of the platform. It was thought that the blowing up of this platform might cause the formation of a denser dust cloud and assist in the development of the early stage of the explosion. The result of this test was also a weak explosion.

TEST 33.

In test 33 two cannon were fired simultaneously, one at the face of the entry and the other in the last cut-through pointing diagonally outby and across the entry. No dust raisers were used. The pressures obtained were slightly higher than in the other tests, but they were still low in comparison with tests made in winter when the mine

was dry. Pressures of 6, 13, and 21 pounds were measured at points 350, 550, and 750 feet, respectively, from the origin.

TESTS 34 AND 35.

Tests 34 and 35 were similar, except that three loaded cars, with brakes set and wheels spragged, were placed at the points E 800, E 900, and E 1000. The English investigators had reported that the pressures developed in an explosion were greatly increased by the presence of obstructions, which in their tests consisted of narrow flanges extending toward the center from the sides of the steel gallery. It was decided to try the car obstructions in order to see if they would give higher pressures. The resulting explosions were still very weak. The mine surfaces were damp and in places wet.

TEST 36.

In test 36 an additional car was placed in the air course to see whether obstructing this passage would give a different result. The pressures in this test increased outby station E 750, 59 pounds being registered at station E 350; the increased pressures were probably due to the drier conditions in the outer end of the entry and the presence of a large amount of the fresh dry dust, which had been carried out from the test zone by the explosion itself.

TEST 45.

Test 45 had a coal-dust zone of 400 feet, ignition being obtained by firing simultaneously two cannon, one being at the face of the main entry and the other in the 1250 cut-through. There were four car obstructions, one in the 1250 cut-through and the others at stations E 1075, E 1000, and E 925; that is, 225, 300, and 325 feet, respectively, from the face of the entry. The explosion was terminated by a shale-dust zone 300 feet long at the end of the coal-dust zone. Low pressures resulted from this arrangement, 5, 3, and 3 pounds being recorded at E 1150, E 950, and E 750, respectively. The obstructing cars were moved only a few feet. The condition of the mine prior to the tests had been damp and in places wet.

TESTS 55, 65, 66, AND 83.

Four tests were made with 600-foot coal-dust zones, in which only one cannon shot and no dust raisers were used. These tests, made from December to February, with the same amount of dust distribution as in the preceding tests, but with dry surfaces, resulted in much higher pressures, as shown in Table 7 (p. 99). Curves of pressure and flame of test 55 are shown in figure 56.

The reader should note that although the presence of moisture on the entry surfaces had much effect, because of the heat absorbed in

evaporating water, in preventing the explosions from developing high pressures and velocities, yet it was possible to get explosions through the wet zones if dry coal dust was present. Therefore, if the watering system is being used to guard against the propagation of widespread explosions it would be necessary to wet thoroughly all dust accumulations, so that no dry dust would be present anywhere in the wetted zone, and the watering should be done frequently enough both to keep old dust wet and to wet new dust before any appreciable amount has collected; otherwise the effectiveness of the watering in rendering the coal dust harmless is more fancied than real.

EFFECT OF VELOCITY AND DIRECTION OF VENTILATING CURRENT ON MINE EXPLOSIONS.

The question of the effect of the ventilating current and the comparative freshness of the air upon the starting of a coal-dust explosion has been a much discussed question in the Indiana, Iowa, Kansas, Oklahoma, and Arkansas coal fields. It has been widely believed in these districts that the danger of explosions was much greater where there was a strong ventilating current of air fresh from the outside than in a quiet atmosphere with no fresh air upon which to feed. Accordingly, the practice of stopping the fan at shot-firing time was very prevalent in the Southwest, it being advocated in some districts that the mine openings be closed as well.

This theory is based on the supposition that a high-velocity air current would furnish more oxygen for the development of the explosion than a low-velocity air current, and, further, that if the openings of the mine were not closed air might enter and, traveling toward the advancing explosion, furnish it with more oxygen. The assumption is that the oxygen in a quiet atmosphere or in a current moving in the same direction as the explosion is not sufficient to feed the explosion and that a supply of oxygen from other points is necessary for its development. The fact remains, however, more explosions per number of mines resulting from shot firing have occurred in the southwestern district than in the vastly greater number of coal mines in other parts of the country where stopping the fan is not practiced. Hence, the State inspectors, being deeply concerned sought reliable information, requesting the bureau to make some tests.

Most of the standard explosion tests have been made with very slow air currents, the velocity probably being below 100 feet per minute. A number of tests were made in which the velocity ranged from 100 to 200 feet per minute. Three special tests (Nos. 120, 138, and 139) were made under such conditions that the results certainly should have shown some effect from the velocity of the air current if this were a factor.

TEST WITH AIR CURRENT OF HIGH VELOCITY.

Test 120 (see fig. 19) was made on June 11, 1914, in the presence of the Mine Inspectors' Institute of America. The high-current velocity of 850 linear feet per minute was used, the point of ignition being in the stub off the last or 1250 cut-through, with the cannon at right angles to the cut-through. The stub and cut-through were used as an ignition zone, pure Pittsburgh coal dust being distributed therein. In the entry and air course outby from this cut-through to stations 700 in either entry a mixture of 60 per cent coal dust and 40 per cent shale dust was distributed at the rate of 4 pounds per foot. Thus the explosion arrangements in the main entry and the air course were the same. The air current entered the main entry and returned in the air course. This symmetrical arrangement permitted comparison of the explosion in two parallel entries having dust distributed in the same manner and amount in each; but the main entry was swept by a high-velocity air current traveling toward the origin and the air course by a current traveling away from it.

When the shot was fired, dust clouds came from both the entry and the air-course openings. Inspection of the flame recorders indicated that the explosion had reached the end of the zones in the two entries. The explosion was relatively weak, with very low velocities, as was intended. This result was attained by using a high percentage of shale dust in the dust mixture. The instrument records indicated that the explosion was very similar in the two entries, the velocities in the air course, which was the "return," being a little greater than those in the entry, which was intaking. It required 3.2 seconds for the flame to reach station E 1150, and 2.9 seconds to reach station A 1150, each being 150 feet from the origin and the flame being compelled to pass around two right-angle turns to the station in either the entry or the air course. The time required for the flame to reach station E 750 in the intaking entry was 6.5 seconds, whereas that required to reach station A 750 in the air course, carrying the return air, was 5.1 seconds. The average velocities indicated by the time of melting of tin foils in the entry and air course, respectively, were 120 and 182 feet per second only; therefore this was a slow explosion. The pressures developed were very light, being 5 pounds at station E 1150 and E 750, respectively, and only 2 pounds at stations A 1150 and A 750.

TESTS WITH NO AIR CURRENT.**TEST 138.**

Two objects were in view—to determine the results and to try out the Rice rock-dust ventilating doors²⁴ that were placed across

²⁴ For description see page 477.

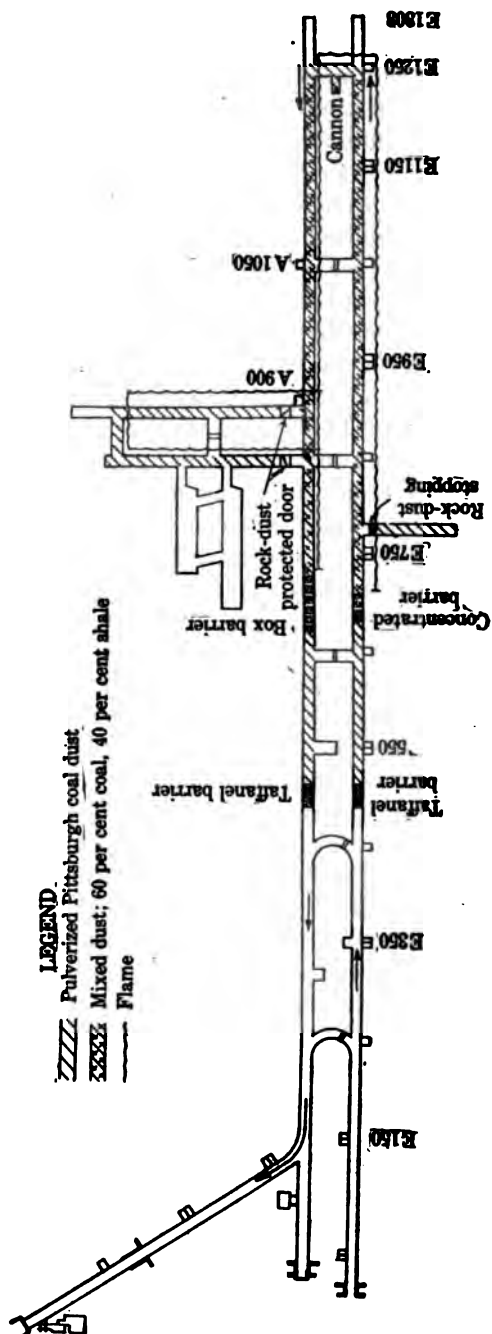


FIGURE 10.—Diagram showing condition of mine as prepared for test 120 and primary results of the explosion.

the entry and air course, the doors being closed, so that no air current would be moving in the explosion zone. Pure Pittsburgh coal dust was distributed at the rate of 2 pounds per foot through the explosion zones to station E 950 and station A 950, respectively, the cannon being placed in the stub, as in test 120. The resulting explosion in the perfectly quiet atmosphere was violent and the flame velocities were high. The ventilating doors extinguished the flame in the respective entries. The pressure and flame curves of test 138 are shown in figure 17 (p. 90).

TEST 139.

The arrangement of igniting shot and zone was the same as in test 138, except that outby a coal-dust ignition zone in the stub and cut-through a mixture of 50 per cent shale dust and 50 per cent coal²⁵ was distributed at the rate of 4 pounds per foot to stations E 950 and A. 950. No air current moved behind the doors, which were acting temporarily as stoppings. The explosion was comparatively strong for mixed dusts, pressures of 25 and 17 pounds being developed at the doors at station E 950 and station A 950, respectively. If closing the explosion zone so near the origin has no effect in preventing an explosion from originating, there can not be any advantage in shutting down the fan or closing all the exits of a coal mine. Each unit of underground space contains sufficient air for explosive combustion of the coal dust; therefore an explosion does not depend on air brought in from a distance.

SHUTTING OFF VENTILATION ENHANCES EXPLOSION HAZARD.

Shutting off the ventilation of a mine that makes any fire damp enhances the risk of an explosion from shot firing because the presence of fire damp at the face where the shots are fired increases greatly the chance of the coal dust being ignited.²⁵

These tests also have a bearing upon a theory that has been advanced both abroad and in this country, namely, that a coal-dust explosion more readily advances when opposed to the intaking current than in the return. The reason given is that the current coming fresh from the outside supplies more oxygen for the combustion of the coal dust. This idea is fallacious, because it is based on the impression that the return air of a mine is much depleted in oxygen. Under normal mining conditions the oxygen content of the mine atmosphere rarely falls as much as 1 per cent, whereas active combustion is not appreciably hindered until the oxygen content has fallen more than 3 per cent.

²⁵ For discussion see Smith, H. I., and Hamon, R. J., Methane accumulations from interrupted ventilation, with special reference to coal mines in Illinois and Indiana: Tech. Paper 190, Bureau of Mines, 1918, pp. 31-42.

The investigations by Clement^{*} show that the lower limit of methane in an explosive mixture with air was raised from 5.5 to only 6.2 per cent when the oxygen was reduced from 20 to 16 per cent, although with this latter percentage of oxygen the upper limit of methane in an explosive mixture with air had fallen from 14.2 to 9.5 per cent.

The formation of carbon dioxide in amounts proportional to the reduction of oxygen has only slight effect upon the explosive limits of mixtures of coal dust and air, as indicated by the Clement investigations with gases. When ignited fine coal dust in air behaves like an inflammable hydrocarbon gas. In test 120, in which there was no difference in the oxygen content between the intake side and the return side, the velocity of the explosion against the ventilating current did not differ materially from that with the current. It is concluded from this and other tests that the direction of the air current at the moment of the explosion has no effect on the development of the explosion.

The first effect of the shock wave of an igniting blast or of an initiatory explosion of gas is the starting of a pressure wave that radiates in all directions at the same velocity as a sound wave, about 1,200 feet per second. This effect momentarily reverses the air current when the latter is traveling in the opposite direction, as is shown clearly by pressure diagrams and by records of air vanes in many of the tests of the experimental mine. If an explosion results, shock waves follow one another rapidly and the advance of the explosion gases and pioneering air waves becomes a continuous movement from the origin along the passageways.

The velocity of a strong ventilating current is very much less than that of the slowest explosion. For example, 800 linear feet per minute or $13\frac{1}{3}$ feet per second is a rapid rate for an air current, whereas the slowest flame velocity that has been recorded in the tests is 25 feet per second. Moreover the pressures of the slowest explosions—2 or more pounds per square inch—are far stronger than ventilation-air pressures, which rarely exceed 0.2 pound per square inch. The effect of a local explosion is, therefore, to reverse immediately any opposing ventilating currents and to quicken the velocity of those going in the same direction, the explosion proceeding without reference to prior ventilation provided always there is pure, dry coal dust enough to feed upon.

The fallacious idea regarding coal-dust explosions "always going against the air" probably arises from the fact that in cold weather the intake air tends to dry the dust, whereas the return air is usually saturated or nearly saturated and the dust in the return-air entries

^{*} Clement, J. K., Influence of inflammable gas on inert gaseous mixtures: Tech. Paper 43, Bureau of Mines, p. 12.

tends to be damp, thus causing conditions for an explosion to be more favorable along the intaking entries than along the return entries. Engineers of the Bureau of Mines who have investigated the causes of explosions have noted that the question whether an explosion travels in one direction or in another depends solely on the presence of enough pure dry dust, and that the air of a working mine always contains oxygen enough to propagate an explosion when the dust is present.

GAS SAMPLES COLLECTED WITH AUTOMATIC SAMPLERS.

METHOD OF SAMPLING AND RESULTS.

A large number of gas or afterdamp samples from the explosion tests were obtained; some merely of the afterdamp in the return air, without reference to any particular period of the explosion, some in an apparatus that operated immediately after the flame had passed, but had no automatic method of sealing, or at least only an imperfect one, and some in the Bureau of Mines automatic samplers. Bureau of Mines sampler model A (described on p. 52) was a three-bottle apparatus actuated by the fusing of a tin-foil at any prearranged point. In the testing, usually the sampler was so set that the first sample was taken before or at the time of the passage of the flame, and the other two samples at prearranged intervals after the operation of the first bottle. To prevent any possibility of stray currents from the batteries that energized the magnets of the sampler wandering to the cable that contained the shot-firing wires, and thus setting off the shot, there was no connection between the sampler circuit and the cable wires to the recording chronograph in the observatory. Consequently it was not known definitely just when the bottle operated, because the sampler foil might not fuse at the same moment as the foil on the opposite side of the entry, which was connected to the chronograph. Therefore with the sampler as first installed the time of sampling could not be fixed definitely, but in each test it was assumed from the flame curve for that particular test.

When the first samples were taken with this apparatus, the tin-foil, the fusing of which operated the sampler, was on the sampler plate, and there was some lag in its fusing as compared with the actual passage of flame. Therefore these samples all represent conditions after the passing of the front of the flame, unless the foil had been torn out in advance by violence. The sampler was in the side of the entry or rib, and more or less unconsumed oxygen was probably trapped near the ribs by the dust cloud. This fact would explain the presence of considerable percentages of oxygen in some samples which are high in CO_2 and CO .

Toward the end of the test period another flame circuit breaker connected to the chronograph was placed alongside the one that operated the sampler. The idea was that the two circuit breakers, being so near together, would operate simultaneously and the record thus obtained would represent the time of operation of the sampler. This opinion was not always verified, because in one test one foil was fused completely, whereas the other was only partly fused and did not open the circuit. Later a method was arranged for making an insulated connection to the breaker head of the first bottle, so that its movement would break a circuit connected to the observatory chronograph, thus recording the exact time the first sample was taken. Such a record was obtained in four tests. The relation of the time of the breaking of this circuit to that of the chronograph foil alongside the sampler foil is given in the following table:

Time of opening of breaker-head circuits and of foil circuit near sampler at station E 1044 in seconds.

	Breaker head.	Foil.
Test 209.....	4. 064	4. 177
Test 211.....	2. 591	2. 552
Test 213.....	4. 454	4. 477
Test 223.....	2. 501	2, 302

In tests 209 and 213 the sampler operated before the chronograph foil, whereas in tests 211 and 223 it operated after the chronograph; therefore the difference in time between the fusing of two foils placed side by side is sufficient to permit a considerable difference in the stage of the explosion in which the sample was taken.

Another error in the time record of the samples taken by this instrument, model A, was caused by the wearing of the clock mechanism. This error, of course, affected only the samples taken in bottles 2 and 3. Consequently only four samples were taken in the earlier tests of which the time is accurately known, namely, the No. 1 samples obtained in tests 209, 211, 213, and 223.

Between the times of making tests 225 and 226, however, a new and better clock mechanism was placed in the model A sampler, and in all subsequent tests the time of the operation of the No. 1 bottle was obtained as described above. The samples obtained in tests 226 and in later tests are therefore more reliable than the earlier ones.

In addition a number of samples were obtained by the Bureau of Mines sampler, model C, described on page 52. This sampler had the advantage that it could be operated automatically by any one of the tin-foils used for velocity records and that a direct and positive time record of the closing of the bottle was made on the chronograph. The sampler obtains a much larger quantity of gas than the model A sampler and has a better closing mechanism; in addition it was so

placed that the samples were obtained from a point in the entry midway between the roof and the floor, about 2 feet 4 inches from one rib. It is felt, therefore, that the results of analyses of samples taken with this instrument are of more value than those obtained with any of the other types. However, the sampler was not developed in time to be used extensively in this series of tests; in fact only one sampler had been completed. In future tests the model C sampler will be used in groups of two or three, like the model A sampler, in order to permit different stages of the explosion being sampled at any one point. As the investigation proceeded it was evident that only those samples that represented the air and gases at a particular time with reference to the passage of the explosion were of much value. Analyses of a large number of these samples are given in Table 8.

112 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 8.—Results of analyses of gases collected in

[All samples were collected at station E 950 unless otherwise

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 950.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis.	
							Laboratory No.	CO ₂ .
67	Ignition test. 600-foot zone, coal dust..	Per cent. None.	.....	A-2 A-3	+0.34 + .86	Lbs. per sq. in. + 7 0	4594 4593	Per cent. 5.03 1.58
76	do.....	None.	620	A-1 A-2 A-3	+ .03 + .34 + .86	+ 1 + 5 + 1	4686 4697 4686	7.96 1.53 0.95
77	Propagation test. 100-foot zone, coal dust; 700-foot zone, 50 per cent roof-shale and 50 per cent coal dust.	None.	430	A-1 A-2	+ .03 + .34	..... .....	4692 4691	10.81 1.62
80	Ignition test. 200-foot zone, coal dust..	None.	1,440	A-1 A-2 A-3	+ .03 + .34 + .86	+18 +18 + 7	4733 4734 4724	14.39 8.55 .91
83	Ignition test. 800-foot zone, coal dust..	None.	2,040	A-1 A-3	+ .03 + .86	..... .....	4748 4746	9.72 7.63
85	Propagation test. 300-foot zone, coal dust; 500-foot zone, roof-shale dust; 200-foot zone, coal dust outby.	None.	300	A-1 A-2 A-3	+ .03 + .34 + .86	..... ..... .....	4844 4847 4843	11.82 12.03 8.12
86	Propagation test. 300 feet Pittsburgh coal dust; 500-foot shale dust zone, 200-foot coal-dust outby.	None.	890	A-1 A-2 A-3	+ .03 + .34 + .86	..... ..... .....	4848 4851 4846	10.68 7.13 8.43
87	Propagation test. 300-foot zone, coal dust; 500-foot zone, roof-shale dust.	None.	470	A-1 A-2	+ .03 + .34	+ 8 + 1	4849 4850	3.15 9.00
88	do.....	None.	580	A-1 A-2 A-3	+ .03 + .34 + .86	+10 + 5 - 3	4841 4842 4839	5.01 6.27 9.00
89	Ignition test. 600-foot zone, coal dust..	None.	1,940	A-1 A-2 A-3	+ .03 + .34 + .86	+25 + 9 - 2	4837 4838 4835	8.15 4.44 7.71
90	Propagation test. 300-foot zone, coal dust; 600-foot zone, pulverized limestone dust.	None.	300	A-1 A-2 A-3	+ .03 + .34 + .86	+13 + 6 - 1	4871 4872 4873	14.13 13.98 10.70
91	do.....	None.	1,840	A-1 A-2 A-3	+ .03 + .34 + .86	+19 +12 0	4870 4868 4869	18.04 8.66 10.75
92	Propagation test. 300-foot zone, coal dust; 200-foot zone, 40 per cent coal and 60 per cent roof shale.	None.	6,666	A-1 A-2 A-3	+ .03 + .34 + .86	+56 +24 0	4970 4965 4966	13.56 7.93 9.98
95	Propagation test. 300-foot zone, coal dust; 800-foot zone, 30 per cent coal and 70 per cent roof shale.	None.	1,320	A-2 A-3	+ .34 + .86	..... .....	4991 4992	8.18 6.57

NOTE 1.—Only those factors of the loading likely to affect the composition of the gas samples are given. Length of loading refers to entry only. Where kind of coal dust is not named, Pittsburgh dust is to be understood. Where the size of dust is not named, pulverized dust is to be understood. "Standard ignition" or "standard propagation" refer to the test methods described under the section "Standard test methods." Where the word "standard" is not used it should not be supplied, as the standard methods were not used.

NOTE 2.—In reporting the time of the samples, the time of rupture of the E 950 tin-foil is taken as zero. Time records before test 209 are approximate and are not to be relied on.

automatic samplers during explosion tests.

indicated. The model C sampler was first used in Test 322.]

Analysis (continued).						Remarks.
O ₂ .	CO.	CH ₄ + C ₂ H ₆ .	N ₂ .	H ₂ .	C ₂ H ₄ .	
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
10.27	5.93	1.16	75.06	1.86	0.69	Gases show considerable distillation and high CO content, the latter indicating excess dust in air.
18.60	0.85	0.20	78.57	0.20	.....	
8.77	3.67	.82	77.15	1.63	.00	Comparison of samples A-1 and A-2 shows increase of oxygen due to air reversal.
17.58	1.88	.65	77.80	.54	.00	
18.24	.85	.40	79.56	.....	.....	
4.05	5.14	.81	77.41	1.78	.00	Note distillation products and high CO content.
17.58	1.28	.63	78.89	.....	.....	
3.41	1.71	.44	79.86	.44	.25	Comparison of samples A-1 and A-3 shows that fresh air entered after explosion, oxygen content rising 14 per cent.
6.74	4.92	1.55	76.25	1.72	.26	
17.61	1.01	.40	78.71	.84	.00	
3.45	7.68	.94	74.42	3.63	.16	High CO and H ₂ content in both samples indicates reduction of water by hot carbon may have occurred, although the hydrogen may be due to distillation. Considerable distillation products present.
6.26	7.63	1.73	73.08	3.45	.22	
5.09	3.64	.55	77.99	.73	.18	Sample A-1 apparently taken ahead of center of explosion, as sample A-2 shows lower oxygen content.
3.01	3.96	.69	78.57	1.74	.00	
9.88	.19	.21	81.50	.00	.10	
7.89	.00	.24	81.19	.00	.00	Note reduction of oxygen by combustion in sample A-1 without formation of CO, such as appears in sample A-2, the oxygen having at the same time increased.
10.06	2.34	.58	78.82	.96	.11	
9.44	1.04	.32	80.77	.00	.00	
16.34	.20	.20	80.11	.00	.00	
7.35	1.42	.46	81.46	.81	.00	
14.46	.30	.30	79.93			Sample A-1 taken in fore part of flame, indicated by decreasing oxygen in the other samples.
11.78	1.67	.56	78.72	.00	.00	
7.28	3.29	.81	78.89	.73	.00	
6.51	5.30	1.10	75.19	3.15	.60	Oxygen content of sample A-2 is much higher than that of either sample A-1 or sample A-3. If sample A-2 was not contaminated by leakage, this indicates a double reversal of the air, the first bringing fresh air past the sampler, the second bringing the burned gases back again. High percentage of distillation products present.
12.43	3.23	1.01	77.17	1.62	.10	
5.55	7.11	1.51	74.71	3.16	.25	
2.39	5.59	.56	75.25	1.93	.15	
3.54	3.17	.60	77.44	1.02	.25	
7.09	2.56	.50	78.10	.88	.17	
0.84	2.61	.51	77.06	.75	.19	Sample A-1 shows very low oxygen content, indicating complete combustion of air, also considerable distillation products and CO, due to excess dust. Sample A-2 shows return of fresh air.
9.85	1.80	.50	78.27	.77	.15	
7.20	2.09	.58	78.78	.55	.05	
1.03	5.36	1.15	75.21	2.38	1.31	Sample A-1 shows nearly complete combustion of air; high CO content is probably due to excess dust. Note high percentage of ethylene and other distillates. Comparison of sample A-1 with samples A-2 and A-3 indicates a double reversal of the air.
7.05	6.14	.97	76.34	2.45	.12	
2.60	7.38	1.51	74.76	3.52	.25	
7.03	4.81	1.02	77.64	1.27	.05	
10.10	3.48	1.05	78.32	.82	.15	

114 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 8.—*Result of analyses of gases collected in automatic*

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 950.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis	
							Laboratory No.	CO ₂ .
		<i>Per ct.</i>	<i>Ft. per sec.</i>		<i>Seconds</i>	<i>Lbs. per sq. ft.</i>		<i>Per ct.</i>
101	Ignition test. 600-foot zone, coal dust.	None.	660	A-1 A-2 A-3	+0.03 + .40 +1.60	..... ..... .....	5044 5052 5043	9.02 9.61 8.64
102	Propagation test. 350-foot zone, coal dust; 900-foot zone, 25 per cent coal dust and 75 per cent limestone dust.	None.	70	A-1 A-2 A-3	+ .03 + .40 +1.80	+ 4 0 0	5067 5056 5055	7.35 8.90 11.97
109	Ignition test. 1,100-foot zone, coal dust.	None.	1,170	A-1 A-2 A-3	+ .05 + .32 +1.52	+ 9 +14 0	5091 5092 5093	9.29 9.35 7.45
111B	Propagation test. 50-foot zone, coal dust; 750-foot zone, 40 per cent coal and 60 per cent shale.	None.	660	A-1 A-2	-.12 + .25	..... .....	5115 5116	.25 3.53
114	Propagation test. 100-foot zone, coal dust; 1,050-foot zone, 60 per cent coal, 40 per cent roof shale.	None.	970	A-1 A-2 A-3	-.04 + .33 +1.53	+ 3 +27 0	5141 5142 5123	.60 .71 7.55
115	Ignition test. 350-foot zone, coal dust.	None.	2,500	A-1 A-2 A-3	-.08 + .34 +1.54	+20 + 6 0	5128 5129 5130	.10 8.11 3.56
161	Standard ignition test. 40 per cent coal and 60 per cent pit shale.	3.44	6,250	A-1 A-2 A-3	+ .02 + .27 +1.47	..... ..... .....	5788 5789 5790	3.85 4.40 11.30
175	Standard ignition test. 40 per cent Pittsburgh coal and 60 per cent pit shale.	None.	430	A-1 A-2 A-3	-.24 + .01 +1.21	+ 9 +15 - 6	5878 5879 5880	Trace. 7.0 3.9
208	Standard ignition test. 50 per cent Beckley seam coal and 50 per cent pit shale.	2.38	520	A-1 A-2 A-3	-.14 + .31 +1.51	..... ..... .....	6124 6125 6126	.43 8.77 1.95
211	Standard ignition test. 50 per cent Upper Freeport coal and 50 per cent pit shale.	None.	810	A-1 A-2 A-3	-.15 + .30 +1.30	+ 9 - 3 - 2	6141 6142 6143	.75 9.15 8.59
213	Standard ignition test. 40 per cent Upper Freeport coal and 60 per cent pit shale.	0.81	650	A-1 A-2 A-3	-.33 + .12 +1.12	+ 3 - 2 - 2	6146 6146 6147	.78 11.98 12.13
223	Standard ignition test. 30 per cent Pittsburgh coal and 70 per cent pit shale.	2.11	510	A-1 A-2 A-3	+ .03 + .42 +1.42	+ 3 - 4 - 2	6217 6218 6219	6.30 10.70 11.26
246	Standard propagation test. 50 per cent pulverized Fire Creek coal and 50 per cent pulverized pit shale.	None.	1,500	A-1 A-3	.00 +1.45	..... .....	6754 6753	3.95 3.40
248	Standard propagation test. 100 per cent $\frac{1}{4}$ -inch (20 per cent 200-mesh) Pittsburgh coal.	None.	760	A-1 A-2 A-3	+2.90 +3.28 +4.35	..... ..... .....	6771 6772 6773	4.68 4.05 .10
261	Standard propagation test. 50 per cent 20-mesh (40 per cent 200-mesh) coal and 50 per cent pulverized pit shale.	None.	880	A-2	+ .30	- 3	6877	3.76
262	Standard propagation test. 100 per cent pulverized coal.	None.	2,500	A-1 A-2	-.02 + .36	+33 + 3	6876 6879	11.83 11.08
265	Standard propagation test. 40 per cent 20-mesh (40 per cent 200-mesh) coal and 60 per cent pulverized pit shale.	None.	320	A-1 A-2 A-3	-.47 - .09 + .98	+ 2 + 2 0	6963 6964 6965	.06 7.70 12.06

samplers during explosion tests—Continued.

Analysis (continued).						Remarks
O ₂	CO	CH ₄ + C ₂ H ₄	N ₂	H ₂	C ₂ H ₄	
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
2.84	7.54	2.05	74.09	8.51	0.55	Note low oxygen and high CO, H ₂ , and CH ₄ in all samples. Shows excess dust in air, distillation, and possible reduction of water by hot carbon.
1.03	9.59	2.35	71.42	6.45	.55	
3.52	6.63	2.01	75.68	8.42	.20	
11.70	.96	.70	79.12	.17	.00	First sample apparently taken early in the flame, as indicated by increasing CO ₂ and CO content through the samples.
9.06	1.66	.84	78.79	.47	.28	
5.69	1.92	.96	79.12	.34	.00	
4.68	5.29	1.06	78.64	3.33	.71	Note high CO, CH ₄ , and H ₂ content.
4.37	6.99	1.65	73.28	4.47	.29	
7.56	5.40	1.13	75.32	2.94	.20	
20.05	.00	.15	79.55	.00	.00	Sample A-1 apparently taken ahead of the flame, but begins to show CH ₄ . Sample A-2 also taken ahead of some of complete combustion.
16.07	.24	.19	79.97	.00	.00	
19.82	.35	.05	79.18	.00	.00	Sample A-2, taken well after passage of head of flame, has high oxygen content, indicating that front of flame does not fill entire entry. Note drop of 15 per cent in oxygen content in sample 3, high CO and high distillation products.
19.59	.20	.30	79.20	.00	.00	
4.35	6.92	1.41	75.96	3.63	.18	
20.30	.00	.00	79.60	-----	-----	Sample A-1, taken just ahead of flame, is nearly pure air. Sample A-2, taken just after flame, shows combustion. Sample A-3 shows recovery of oxygen content from air-current reversal.
9.42	1.07	.36	81.04	-----	-----	
13.14	3.21	.86	77.03	2.21	-----	
13.51	2.22	.95	77.98	1.12	.37	The three samples show change in composition of air from start to end of flame. Note low oxygen and high CO and H ₂ content in sample A-3.
12.77	2.72	.82	78.51	.78	.00	
1.28	6.46	1.09	76.48	3.19	.20	
20.8	.00	.1	79.1	.00	.00	High oxygen content in sample A-3 was due to unconsumed air returning toward the face of the entry after the flame was extinguished, confirming evidence of this being given by the air direction indicator at station E 960.
12.2	.4	.4	80.0	Trace.	.00	
15.7	.9	.5	79.0	Trace.	.00	
19.69	Trace.	.87	79.01	.00	.00	Note distillation products in last sample.
5.60	2.15	2.18	80.77	.53	.00	
20.33	.47	1.25	76.02	.00	.00	
19.90	.14	.04	79.17	.00	.00	Shows change of composition of air with passage of flame.
6.67	2.69	.91	79.32	1.26	.00	
6.99	3.31	1.29	77.92	1.90	.00	
19.43	.02	.75	78.80	.22	.00	Note high CO and H ₂ and low oxygen content in third sample.
5.34	.44	.10	82.14	.00	.00	
3.82	1.07	.44	82.36	.18	.00	
10.22	2.15	1.61	78.55	1.17	.00	Considerable distillation products in samples A-1 and A-2. Reversal of gas movement brought fresh air before sample A-3 was taken.
4.67	3.02	1.32	78.74	1.55	.00	
3.73	8.04	1.41	78.53	2.04	.00	
14.44	1.70	.88	78.87	.16	-----	Sample A-1 coincident with flame photograph record at station E 960.
15.78	1.48	.56	78.74	.04	-----	
13.26	2.36	.26	78.76	.68	-----	
12.18	2.28	.55	78.76	1.18	-----	Compare samples A-1 and A-3; shows atmosphere before and after flame.
20.68	-----	-----	79.22	-----	-----	
13.97	2.34	Trace.	78.46	1.29	.18	
6.00	.72	-----	80.63	.27	.56	Sample A-1 coincident with flame photograph record at station E 960.
6.24	.65	-----	81.66	.14	.28	
20.87	.00	.02	79.05	.00	-----	Compare samples A-1 and A-3; shows atmosphere before and after flame.
11.07	.34	.06	80.83	.00	-----	
5.16	1.25	.34	80.88	.29	-----	

116 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 8.—Result of analyses of gases collected in automatic

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 960.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis.	
							Laboratory No.	CO ₂ .
		Per ct. None.	Ft. per sec. 960		Seconds.	Lbs. per Sq. in.		Per ct.
274	Standard propagation test. 70 per cent $\frac{1}{4}$ -inch (20 per cent 200-mesh) coal and 30 per cent pulverized pit shale.			A-1 A-2 A-3	-.03 +.80 +1.37	+14 +4	7044 7045 7046	0.42 9.16 9.55
275	Standard propagation test. 50 per cent 20-mesh (40 per cent 200-mesh) coal and 50 per cent pulverized pit shale.	None.	300	A-1 A-2 A-3	-.18 +.20 +1.27	+6 +5 -2	7047 7048 7049	.07 2.44 9.23
277	Standard propagation test. 50 per cent 20-mesh (20 per cent 200-mesh) coal and 50 per cent pulverized pit shale.	None.	290	A-1 A-2 A-3	-.41 -.03 +1.04	..... ..... .....	7056 7057 7058	.07 6.37 11.79
286	Standard ignition test. 40 per cent pulverized Sewell coal and 60 per cent pulverized pit shale.	0.84	350	A-1 A-3	-.37 +1.09	+3 0	7196 7197	.08 12.32
287	Standard propagation test. 50 per cent 20-mesh (20 per cent 200-mesh) Sewell coal and 50 per cent 20-mesh pit shale.	None.	110	A-1 A-2 A-3	-.74 -.31 +.88	+5 +3 0	7198 7199 7200	.07 .73 6.48
288	Standard propagation test. 40 per cent 20-mesh (20 per cent 200-mesh) Sewell coal and 60 per cent 20-mesh pit shale.	None.	70	A-1 A-3	-1.35 +.10	+2 -1	7201 7202	.03 9.26
290	Standard propagation test. 100 per cent pulverized. Pittsburgh coal at 0.3 pounds per foot.	None.	210	A-1 A-2 A-3	-.01 +.37 +1.44	+9 0 -1	7203 7204 7205	1.10 4.06 5.48
292	Standard ignition test. 50 per cent pulverized Indiana No. 5 coal and 50 per cent pulverized pit shale.	None.	3,500	A-1 A-2 A-3	-.01 +.37 +1.44	+30 +13	7206 7207 7208	.61 5.47 3.30
302	Standard propagation test. 40 percent 20-mesh, (40 per cent 200-mesh) Indiana No. 5 coal and 60 per cent 20-mesh pit shale.	None.	550	A-1 A-2 A-3	-.05 +.33 +1.40	+9 +3 0	7306 7307 7308	.57 14.10 .20
304	Standard ignition test. 50 per cent pulverized Sewell coal and 50 per cent pulverized pit shale.	None.	650	A-1 A-2 A-3	-.02 +.36 +1.43	+8 -1 -1	7348 7349 7350	1.07 6.01 12.30
319	Standard ignition test. 50 per cent pulverized Owl Creek coal and 50 per cent pit shale.	None.	450	A-1 A-2 A-3	-.18 +.20 +1.27	+10 +5 0	7471 7472 7473	.15 13.48 3.57
320	Standard propagation test. 60 percent $\frac{1}{4}$ -inch (20 per cent 200-mesh) Pittsburgh coal and 40 per cent pulverized pit shale.	None.	210	A-1 A-2 A-3	-.59 -.21 +.86	+4 +4 0	7474 7475 7476	.10 .93 11.97
322	Standard propagation test. 60 percent 20-mesh (20 per cent 200-mesh) Owl Creek coal and 40 per cent 20-mesh pit shale.	None.	180	C-1 A-1 A-2 A-3	-1.19 -.43 -.05 +1.02	+3 +5 +1 0	7522 7519 7520 7521	.10 .13 1.73 10.10
329	Standard propagation test. 25 percent 20-mesh (40 per cent 200-mesh) Pittsburgh coal and 75 per cent 20-mesh pit shale.	1.44	75	A-1 C-1 A-2 A-3	-1.27 -1.23 -.80 +.16	+2 +2 0 - $\frac{1}{2}$	7575 7576 7576 7577	.10 .23 .27 5.45
333	Standard propagation test. 75 percent pulverized coal and 25 percent water.	None.	1,700	A-1 A-2 C-1	-.06 +.22 +.4	+14 +27	8126 8125 8123	.12 7.73 5.02
334	Standard propagation test. 50 percent pulverized Pittsburgh coal, 40 per cent pulverized pit shale and 10 per cent water.	None.	1,700	A-1 A-2 C-1 A-3	-.09 +.21 +.52 +1.07	+17 +15 +7 -1	8124 8122 8120 8121	.10 11.16 8.04 10.65

samplers during explosion tests—Continued.

Analysis (continued).						Remarks.
O ₂ .	CO.	CH ₄ + C ₂ H ₄ .	N ₂ .	H ₂ .	C ₂ H ₄ .	
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
20.35	0.07	0.03	79.13	0.00	0.00	Sample A-1, taken just ahead of flame, hardly altered from normal air. Sample A-3, taken after the flame, gives high CO, probably due to excess dust in the air, and more than 5 per cent distillation products (CH ₄ , H ₂ , and C ₂ H ₄).
6.08	3.09	1.87	78.30	1.52	.00	
3.67	5.60	1.83	75.51	3.21	.63	
20.82	.00	.03	79.08	.00	.00	Note high CO ₂ and small CO content in sample A-3.
17.75	.18	.00	79.49	.14	.00	
9.70	.17	.00	80.86	.05	.00	
20.87	.00	.05	79.01	.00	.00	Note high CO ₂ , but low CO in sample A-3.
12.37	.17	.01	80.50	.08	.00	
4.99	.86	.53	81.79	.05	.00	
20.53	-----	.82	78.57	-----	-----	Illustrates different composition of air before and after passage of flame. Note higher methane than of CO ₂ in A-1.
4.06	.91	.22	81.88	.41	-----	
20.84	-----	.02	79.07	-----	-----	
19.95	.06	.01	79.20	.02	-----	
12.61	.33	.15	80.37	.06	-----	
20.92	-----	Trace.	79.05	-----	-----	
9.09	.33	.60	81.15	.17	-----	
19.49	.09	.01	79.31	-----	-----	
16.02	.09	.01	79.81	.01	-----	
14.47	.00	.02	80.08	-----	-----	Sample A-1, taken coincident with flame, shows little combustion, indicating that front of flame did not fill entire entry. Considerable CO present in sample A-2.
20.20	.07	.08	79.08	.01	-----	
11.99	3.72	1.09	76.79	.94	-----	
16.10	2.03	.51	77.86	.00	-----	Note gain of oxygen content from samples A-2 to A-3. Air-movement detector gave reversal of air in this period.
20.30	.09	.03	79.01	-----	-----	
3.45	.79	.38	81.24	.04	-----	
20.58	.07	.02	79.13	-----	-----	There was no reversal of air before sample A-3 in this test. Compare with sample A-3 in test 302, where reversal occurred.
19.26	.20	.00	79.47	.00	-----	
13.31	.25	.03	80.34	.06	-----	
4.64	1.40	.80	80.82	.04	-----	
20.71	.06	-----	79.04	.05	-----	
4.91	.24	.17	81.20	-----	-----	
13.70	.88	.37	79.39	.09	-----	Considerable distilled methane in sample A-3.
20.81	.15	.01	78.98	.00	-----	
19.72	.00	.12	79.23	.00	-----	
5.21	1.13	.43	80.92	.34	-----	
20.82	.07	.03	78.98	.00	-----	
20.75	.01	.05	79.04	.01	-----	
18.77	.23	.04	79.23	.00	-----	
8.60	.13	.08	81.09	.00	-----	
20.35	Trace.	1.20	78.35	-----	-----	
20.27	-----	1.37	78.23	-----	-----	
20.43	.15	.92	78.23	-----	-----	
13.48	.34	.39	80.34	-----	-----	
20.66	-----	.06	79.16	-----	-----	Note high CO and H ₂ content in A-3 samples and C-1, caused by decomposition of water by hot carbon.
5.07	7.55	.97	73.71	4.98	-----	
12.19	3.55	.97	77.15	1.12	-----	
20.82	-----	.04	79.04	-----	-----	Note high CO and H ₂ content, caused by decomposition of water; also, a large amount of methane was distilled.
2.14	6.30	1.48	75.49	3.43	-----	
6.74	5.25	1.73	73.68	4.56	-----	
2.30	4.47	2.88	76.08	2.67	-----	

118 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 8.—*Result of analyses of gases collected in automatic*

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 950.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis	
							Laboratory No.	CO ₂
		<i>Per ct.</i>	<i>Ft. per sec.</i>		<i>Seconds.</i>	<i>Lbs. per Sq. in.</i>		<i>Per ct.</i>
336	Standard propagation test. 60 per cent 20-mesh (20 per cent 200-mesh) coal, 30 per cent 20-mesh pit shale, and 10 per cent water.	None.	180	A-1 A-2 A-3	-0.36 - .03 + .83	+ 3 + 1 0	8175 8176 8177	0.42 7.04 11.72
342	Standard propagation test. 50 per cent 20-mesh (40 per cent 200-mesh) coal, 40 per cent 20-mesh pit shale, and 10 per cent water.	None.	1,350	C-1	+ .28	+ 4	8252	11.71
344	Standard propagation test. 70 per cent 20-mesh (20 per cent 200-mesh) coal and 30 per cent 20-mesh pit shale.	None.	1,350	C-1	+ .30	+ 8	8254	10.38
345	Standard propagation test. 50 per cent 20-mesh (20 per cent 200-mesh) Miller coal and 50 per cent 20-mesh pit shale.		1,500	C-1	+ .14	+ 9	8275	5.74
346	Standard ignition test. 70 per cent 20-mesh (20 per cent 200-mesh) Miller coal and 30 per cent 20-mesh pit shale.	None.	1,560	C-1	+ .10	+ 17	8276	13.40
347	Standard ignition test. 100 per cent 20-mesh (20 per cent 200-mesh) Miller coal.	None.	7,500	C-1	Bet. + .10 and + .57	Bet. + 32 and + 14	8277	8.39
350	Standard propagation test. 60 per cent 20-mesh (10 per cent 200-mesh) Miller coal and 40 per cent 20-mesh pit shale.	None.	550	C-1	+ .21	+ 9	8292	5.02
355	Standard ignition test. 80 per cent 20-mesh (10 per cent 200-mesh) coal and 20 per cent 20-mesh pit shale.	None.	240	A-1 A-2 C-1 A-3	- .45 - .15 - .06 + .71	+ 3 + 5 + 5 + 1	8316 8318 8320 8319	.17 4.22 9.57 12.67
356	Standard ignition test. 100 per cent 20-mesh (10 per cent 200-mesh) coal, E seam.	None.	2,500	C-1	+ .46	+ 9	8321	6.40
357	Standard ignition test. 70 per cent 20-mesh (10 per cent 200-mesh) Miller coal, and 30 per cent 20-mesh pit shale.	None.	350	C-1	+ .08	0	8357	5.61
358	Standard ignition test. 100 per cent 20-mesh (10 per cent 200-mesh) coal, E seam.	None.	4,500	A-1 A-2 C-1 A-3	- .02 + .28 + .83 + 1.14	+73 +21 + 6 + 2	8358 8359 8361 8360	.09 9.32 1.92 4.53
360	Standard propagation test. 60 per cent 20-mesh (10 per cent 200-mesh) E-seam coal and 40 per cent 20-mesh pit shale.	None.	1,150	A-1 A-2 C-1 A-3	- .21 + .09 + .13 + .65	+ 9 +10 + 9 - 1	8362 8363 8365 8364	.12 15.17 8.00 3.01
361	Standard propagation test. 50 per cent pulverized E-seam coal and 50 per cent pulverized pit shale.	None.	610	A-1 A-2 A-3	- .19 + .11 + .97	+ 9 + 8 - 1	8369 8381 8382	.36 11.96 12.06
362	Standard propagation test. 50 per cent 20-mesh (10 per cent 200-mesh) E-seam coal, and 50 per cent 20-mesh pit shale.	None.	630	A-1 A-2 A-3	- .31 - .01 + .85	+ 7 + 9 - 1	8383 8384 8385	.15 3.89 10.66
365	Standard ignition test. 70 per cent 20-mesh (10 per cent 200-mesh) E-seam coal, and 30 per cent 20-mesh pit shale.	None.	240	A-1 A-2 C-1 A-3	- .26 + .04 + .54 + .80	+ 6 +12 - 1 - 1	8425 8426 8428 8427	.14 12.91 12.42 12.40

samplers during explosion tests—Continued.

Analysis (continued).						Remarks.
O ₂	CO.	CH ₄ + C ₂ H ₆	N ₂	H ₂	C ₂ H ₄	
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
20.62	.....	0.00	78.96	.....	.....	
11.81	.46	.35	80.22	0.12	.....	
5.96	.82	.40	80.86	.24	.....	
1.01	7.95	1.03	73.61	4.69	.....	Note high content of CO and H ₂ and low content of oxygen. The CO is probably due partly to decomposition of water and partly to excess dust in the air, the latter being indicated by the very low oxygen content.
.37	9.72	.74	73.64	5.15	.....	Note the low content of oxygen and high content of CO and H ₂ . Indicates that excess dust and distillation were principal causes, as the moisture content was low.
12.04	2.10	.72	78.87	.53	.....	
1.29	5.98	2.39	72.99	4.00	.....	Note low content of oxygen and high content of CH ₄ and H ₂ . H ₂ in this sample is probably due mainly to distillation, as there was little moisture in the mixed dust. High CO is probably from excess dust.
.74	11.66	4.21	68.84	6.16	.....	This sample has the largest percentage of CO and distilled CH ₄ ever obtained. The CO is probably due mainly to incomplete combustion, with distillation and reduction of water as secondary causes. The H ₂ is mainly from distillation, but some decomposition of water probably took place.
11.63	3.26	1.18	77.13	1.79	.....	Considerable amount of distillate.
20.53	.....	.04	79.26	.....	.....	
15.46	.23	.00	80.09	.....	.....	
7.00	2.87	.97	79.78	.11	.....	
1.60	4.03	1.12	78.18	2.40	.....	
5.84	8.49	1.87	72.01	5.39	.....	Note high percentage of distillates. It is possible that the E-seam coal yields its volatile matter more easily than Pittsburgh coal, but it can not be definitely proved from the samples.
12.27	1.42	.30	79.68	.72	.....	
20.79	.....	.06	79.06	.....	.....	
1.02	8.92	1.88	72.19	6.47	.....	Samples show high content of CO, CH ₄ , and H ₂ , indicating distillation and excess of dust in air.
17.40	2.01	.37	78.27	.63	.....	
10.58	6.12	1.41	73.54	3.82	.....	
20.77	.....	.01	79.10	.....	.....	
.57	.67	.14	83.45	.....	.....	
8.60	2.67	.90	79.83	.....	.....	
16.03	.96	.24	79.31	.45	.....	
20.61	.....	.....	78.89	.14	.....	Shows change of composition of air with passage of flame.
5.46	.....	.....	82.56	.00	.....	
2.97	1.24	1.24	80.71	1.76	.....	
20.85	.....	.....	79.00	.....	.....	
15.54	.38	.08	80.11	.....	.....	
6.08	1.27	.69	81.07	.33	.....	
20.87	.....	.....	78.99	.....	.....	
4.42	.35	.....	82.32	.....	.....	High CO content and low oxygen content in samples C-1 and A-3 may be due to excess dust in the air.
3.00	2.06	.69	80.60	.23	.....	
2.98	2.28	.68	80.78	.88	.....	

TABLE 8.—Result of analyses of gases collected in automatic

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 950.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis.	
							Laboratory No.	CO ₂ .
		Per cent.	Ft. per sec.		Seconds	Lbs. per Sq. in.		Per cent.
368	Standard ignition test. 60 per cent pulverized E-seam coal and 40 per cent pulverized pit shale.	None.	500	A-1 C-1 A-2 A-3	—0.06 + .24 +1.10	+11 + 9 — 1 + $\frac{1}{2}$	8473 8476 8474 8475	6.14 12.08 8.26 13.24
370	Standard ignition test. 50 per cent pulverized E-seam coal and 50 per cent pulverized pit shale.	.95	3,000	A-1 A-2 C-1 A-3	 + .30 + .38 +1.16	+15 + $\frac{1}{2}$ + $\frac{1}{2}$ 0	8477 8478 8480 8479	.26 4.22 8.35 8.28
373	Standard propagation test. 50 per cent pulverized coal, 30 per cent pulverized pit shale, and 20 per cent water.	None.	500	A-1 A-2 C-1	— .50 — .29 + .30	+ 4 + 4 + 1	8501 8502 8503	.32 9.91 6.29
383	Standard propagation test. 40 per cent 20-mesh (40 per cent 200-mesh) British Columbia coal and 40 per cent 20-mesh pit shale.	1.75	450	A-1 A-2	— .12 + .21	+19 +11	8628 8629	.18 11.39
384	Standard propagation test. 60 per cent 20-mesh (40 per cent 200-mesh) British Columbia coal and 40 per cent 20-mesh pit shale.	None.	900	A-1 C-1 A-2 A-3	— .21 + .10 + .12 +1.06	+ 6 + 8 + 7 — 2	8630 8633 8631 8632	.14 7.44 3.90 13.90
385	Standard propagation test. 30 per cent 20-mesh (40 per cent 200-mesh) British Columbia coal and 70 per cent 20-mesh pit shale.	2.39	1,170	A-1 A-2 C-1 A-3	— .34 — .01 + .23 + .93	+ 8 + 9 + 5 — 1	8634 8635 8637 8636	.08 3.02 14.49 11.81
386	Standard ignition test. 60 per cent pulverized British Columbia coal and 40 per cent pulverized pit shale.	None.	1,600	C-1 A-1 A-2 A-3	+ .06 + .13 + .46 +1.40	+10 + 9 + 2 0	8664 8661 8662 8663	10.46 8.35 9.05 1.38
388	Standard propagation test. 50 per cent pulverized British Columbia coal and 50 per cent pulverized pit shale.	None.	530	A-1 C-1 A-2 A-3	+ .01 + .02 + .34 +1.26	+10 +10 + 2 0	8665 8668 8666 8667	.45 2.54 10.85 .94
389	Standard propagation test. 40 per cent 20-mesh (40 per cent 200-mesh) British Columbia coal and 60 per cent 20-mesh pit shale.	.96	2,400	A-1 C-1 A-2	+ .01 + .06 + .34	+ 7 + 8 + 5	8669 8672 8673	.29 11.09 3.50
393	Standard propagation test. 60 per cent 20-mesh (20 per cent 200-mesh) British Columbia coal and 40 per cent 20-mesh pit shale.	None.	280	A-1 C-1 A-2 A-3	+ .18 + .26 + .51 +1.45	+ 6 + 5 0 — $\frac{1}{2}$	8716 8719 8717 8718	.86 15.14 7.90 2.08
394	Standard propagation test. 50 per cent 20-mesh (20 per cent 200-mesh) British Columbia coal, and 50 per cent 20-mesh pit shale.	None.	170	C-1 A-1 A-2 A-3	— .28 — .28 + .06 + .99	0 0 0 — 1	8723 8720 8721 8722	4.78 .09 2.79 .96
395	Standard propagation test. 30 per cent 20-mesh (20 per cent 200-mesh) British Columbia coal, and 70 per cent 20-mesh pit shale.	1.83	500	C-1 A-1 A-2 A-3	— .04 — .01 + .32 +1.26	+ 9 + 9 + 4 0	8727 8724 8725 8726	8.87 .80 7.93 .21
400	Standard propagation test. 40 per cent pulverized British Columbia coal and 60 per cent pulverized pit shale.	None.	1,000	A-1 A-2 A-3	+ .02 + .36 +1.29	+12 + 7 0	8797 8798 8799	.35 14.11 .26
403	Standard ignition test. 30 per cent pulverized Kentucky coal and 70 per cent pulverized pit shale.	1.90	680	A-1 A-2 C-1 A-3	 + .22 + .26 +1.16	 + 7 + 5 — 1	8815 8820 8819	14.91 12.21 .47
404	Standard ignition test. 50 per cent pulverized British Columbia coal and 50 per cent pulverized pit shale.	None.	960	A-1 A-2 C-1 A-3	— .17 + .16 + .24 +1.10	+11 +11 + 8	8821 8822 8824 8823	.16 12.46 12.12 11.59

samplers during explosion tests—Continued.

Analysis (continued).						Remarks.
O ₂	CO.	CH ₄ + C ₂ H ₆	N ₂	H ₂	C ₂ H ₄	
Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	
12.33	0.51	0.06	80.96			Samples A-1 and C-1 were taken at nearly the same instant. Note difference in composition of samples taken at rib and 2½ feet therefrom. Sample A-3 corresponds in composition to sample C-1. Note high percentage of distilled gas present.
2.06	.61	2.42	82.23	.....	.....	
10.20	.53	.01	81.00	.....	.....	
2.12	.54	3.12	80.96	.....	.....	
.....						
20.46		.90	78.38			The CO and H ₂ are probably due to decomposition of water.
14.82	.37	.14	79.75	.....	.....	
8.49	2.35	1.58	79.23	.....	.....	
8.75	.72	1.44	80.77	.....	.....	
.....						
20.76	.14		78.78			Note low content of oxygen and high content of CO and H ₂ in sample A-2.
7.67	1.44	.45	79.95	.58	.....	
11.54	2.15	.60	78.19	1.23	.....	
.....						Samples C-1 and A-2 show difference of composition at side and near center of flame.
20.04	.....	1.92	77.86	.....	.....	
2.22	2.24	1.34	80.12	2.69	.....	
.....						
20.72	.16	.00	78.96	.....	.....	
11.45	1.12	.42	79.57			Oxygen content of sample C-1 is very low.
15.68	.35	.00	80.07	.....	.....	
2.50	1.03	.23	81.65	.69	.....	
.....						
20.12	.....	2.38	77.42	.....	.....	
16.78	.51	.97	78.72			Samples A-1, taken 0.07 seconds after sample C-1, both being taken after tin-foil rupture at station E 950, has 4 per cent more oxygen, showing comparatively incomplete combustion near rib.
.74	1.11	.60	82.97	.....	.....	
5.80	.78	1.45	80.16	.....	.....	
.....						
6.25	1.87	.98	80.44	.....	.....	
10.23	.26	.07	81.00			Compare samples A-1 and C-1 for difference of composition at rib and near center. Only 0.04 second separates the two samples.
9.21	.74	.39	80.61	.....	.....	
18.50	.28	.19	79.65	.....	.....	
.....						
20.28	.05	.03	79.19	.....	.....	
17.13	.93	.36	79.04			Compare samples A-1, C-1, and A-2. In the air near the center the oxygen was almost entirely consumed, but in that near the rib a large percentage was left.
7.36	.61	.21	80.97	.....	.....	
19.54	.17	.09	79.26	.....	.....	
.....						
20.08	.....	.89	78.74	.....	.....	
5.19	.83	1.02	81.87			Samples C-1 and A-1 were taken at the same time. Sample C-1 has 6 per cent less oxygen than sample A-1.
15.73	.38	.43	79.96	.....	.....	
.....						
19.29	.20	.03	79.62	.....	.....	
1.46	2.21	.41	80.78	.....	.....	
11.02	.36	.03	80.69			Compare composition of sample C-1 and A-1, both taken at nearly the same instant.
18.19	.16	.01	79.56	.....	.....	
.....						
14.97	.30	.06	79.89	.....	.....	
20.56	.09	.00	72.24	.....	.....	
17.31	.24	.00	79.75			Note recovery in oxygen content from sample A-2 to sample A-3, owing to reversal of the air.
19.32	.12	.00	79.70	.....	.....	
.....						
7.33	1.96	1.74	80.11	.....	.....	
18.96	.....	2.01	78.21	.....	.....	
9.48	.15	.15	82.29			In samples A-2, C-1, and A-3 note high content of CO and distillation products, and low content of oxygen.
20.37	.12	.02	79.28	.....	.....	
.....						
19.97	.15	.....	79.58	.....	.....	
2.48	2.19	.64	80.10	.48	.....	
20.48	.08	.06	79.12			In samples A-2, C-1, and A-3 note high content of CO and distillation products, and low content of oxygen.
.....						
1.89	.37	.21	82.71	.....	.....	
4.20	1.57	.84	81.06	.12	.....	
19.58	.07	.04	79.84	.....	.....	
.....						In samples A-2, C-1, and A-3 note high content of CO and distillation products, and low content of oxygen.
20.64	.08	.02	79.10	.....	.....	
1.92	4.99	2.22	75.73	2.68	.....	
1.48	4.82	2.46	77.01	1.11	.....	
2.90	4.64	2.01	75.96	2.90	.....	

TABLE 8.—Result of analyses of gases collected in automatic

Test No.	Kind of test (see Note 1).	Gas used.	Flame velocity at station E 950.	Type of sampler and number of bottle.	Time of sample (see Note 2).	Pressure at station E 950 at time of sampling.	Analysis.	
							Laboratory No.	CO ₂ .
		<i>Per ct.</i>	<i>Ft. per sec.</i>		<i>Seconds.</i>	<i>Lbs. per sq. in.</i>		<i>Per ct.</i>
406	Standard propagation test. 40 per cent 20-mesh (40 per cent 200-mesh) Kentucky coal and 60 per cent 20-mesh pit shale.	None.	230	C-1 A-1 A-2 A-3	—0.34 — .01 + .32 +1.26	+ 4 + 5 + 1 0	8844 8847 8846 8845	0.14 1.49 7.63 12.57
409	Standard propagation test. 30 per cent pulverized Kentucky coal and 70 per cent pit shale.	None.	670	A-1 C-1 A-2 A-3	— .02 + .12 + .25 +1.15	+ 9 + 7 + 3 — 1	8890 8893 8891 8892	.89 15.68 11.06 14.15
432	Standard propagation test. 60 per cent 20-mesh (10 per cent 200-mesh) Pittsburgh coal, 35 per cent 20-mesh pit shale, and 5 per cent water.	None.	370	A-1 A-2 C-1 A-3	— .50 — .17 — .15 + .77	+ 4 + 5 + 5 0	9100 9101 9103 9102	.14 6.30 12.94 11.58
434	Standard propagation test. 30 per cent 20-mesh (10 per cent 200-mesh) coal and 70 per cent 20-mesh pit shale.	1.8	100	A-1 C-1 A-2 A-3	+ .53 + .62 + .84 +1.75	— 1 — 1 — 1 — 1	9325 9328 9326 9327	5.13 10.79 4.11 9.48
441	Standard ignition test. 60 per cent 20-mesh (10 per cent 200-mesh) coal and 40 per cent 20-mesh pit shale.	1.80	1,000	C-1 A-2	+ .10 + .20	+ 6 + 5	9398 9396	11.49 4.83
450	Standard ignition test. 100 per cent 20-mesh (20 per cent 200-mesh) Montana coal.	None.	600	A-1 A-2 A-3	— .03 + .28 +1.19	+ 6 + 1 + ½	9455 9456 9457	.39 10.73 12.06
454	Standard ignition test. 70 per cent 20-mesh (20 per cent 200-mesh) Montana coal, 2 per cent water, and 28 per cent 20-mesh pit shale.	1.96	2,000	A-1 A-2 A-3 C-1	+ .03 + .34 +1.25 +2.58	+ 4 0	9470 9471 9472 9473	 11.24 8.66 12.06
456	Standard propagation test. 30 per cent pulverized Montana coal and 70 per cent pulverized pit shale.	None.	350	A-1 C-1 A-2 A-3	— .02 + .14 + .29 +1.20	+ 9 + 7 + 1	9507 9510 9508 9509	.37 15.96 3.38 10.87
466	Standard propagation test. 70 per cent 20-mesh (20 per cent 200-mesh) Illinois coal and 30 per cent 20-mesh pit shale.	None.	400	C-1 A-1 A-2 A-3	+ .02 + .13 + .43 +1.35	+ 7 + 8 + 4 — ½	9728 9725 9726 9727	2.53 .89 7.53 6.50
468	Standard ignition test. 100 per cent 20-mesh (20 per cent 200-mesh) coal.	None.	1,200	A-1 C-1 A-3	— .04 + .08 +1.18	+14 +10 — ½	9747 9750 9749	.11 12.4 11.6
480	Standard propagation test. 40 per cent 20-mesh (20 per cent 200-mesh) coal and 60 per cent 20-mesh pit shale.	2.16	550	A-1 C-1 A-2 A-3	— .01 + .12 + .30 +1.21	+ 8 + 7 + 2 0	9751 9754 9752 9753	.34 12.5 5.67 1.42

SAMPLES COL-

462	Propagation test, 1 butt. 60 per cent 20-mesh (10 per cent 200-mesh) coal and 40 per cent 20-mesh pit shale.	None.	160	C-1	+ .58	.....	9578	6.30
463	Propagation test, 1 butt. 50 per cent 20-mesh (10 per cent 200-mesh) coal and 50 per cent 20-mesh pit shale.	None.	140	C-1	+ .48	.....	9579	14.36
477	No. 3 room ignition test. 50 feet, 100 per cent 20-mesh (10 per cent 200-mesh) coal; remainder of room, 100 per cent pulverized Pittsburgh coal.	None.	None.	C-1	+ .08	.....	9705	11.24

• Time of sampling as indicated by fusing of tin-foil at 1B-250.

samplers during explosion tests—Continued.

Analysis (continued).						Remarks.
O ₂	CO	CH ₄ + C ₂ H ₄	N ₂	H ₂	C ₂ H ₄	
<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	
20.50	0.14		79.13			
18.80	.28		79.34			
11.40	.45	0.06	80.46			
4.72	.97	.73	80.85	0.16		
19.67	.16	.04	79.24			Compare samples A-1, C-1, and A-2, to obtain relative of position of sample to composition.
1.97	1.47	1.23	80.46	.25	.....	
7.51	.31	.11	81.01	.....	.....	
3.14	1.20	.58	80.63	.30	.....	
20.89	.....	.04	78.93	.....	.....	
12.53	.52	.15	80.50			Compare oxygen content of samples A-2 and C-1, taken 0.02 second apart, showing effect of position; also note high content of CO and distillation products.
1.01	3.44	2.09	77.97	2.55	.....	
4.10	2.63	1.07	79.56	1.06	.....	
13.15	1.42	.35	79.00	.95	0.00	Compare composition of samples A-1, C-1, and A-2 for relation of point of sampling to composition.
6.16	.00	.17	82.85	.00	.00	
14.97	.12	.10	80.51	.19	.00	
6.83	1.15	.36	81.85	.30	.00	
.51	5.50	.61	79.92	1.50	.47	
14.18	.18	.18	80.63			Note low content of oxygen and high content of CO and distillation products in sample C-1, indicating excess of dust in air.
20.48	.08	.11	78.94	.....	.....	
7.84	.....	.14	81.29	.....	.....	
6.37	.87	.44	79.67	.57	.....	
20.33	.....	1.81	77.86	.00	.....	
5.67	1.44	.38	80.07	1.20		Compare samples A-1, C-1, and A-2 for relation of point of sampling to composition.
8.74	.35	.27	81.69	.27	.....	
2.47	3.67	.81	78.27	2.53	.16	
20.55	1.12	.02	78.94	.....	.....	
3.20	.85	.64	78.85	.....	.49	
16.65	1.51	.25	77.96	.25		Compare samples A-1 and C-1 for relation of point of sampling to composition.
7.22	1.26	.43	80.04	.18	.....	
17.43	.29	.05	79.70	.....	.....	
19.73	.07	.04	79.27	.....	.....	
11.25	.14	.....	81.08	.....	.....	
6.94	2.37	.91	79.18	1.10		In sample C-1 note low content of oxygen and high content of CO and distillation products.
20.83	.02	.02	79.02	.....	.....	
.4	5.6	4.1	74.6	2.9	.....	
4.8	2.8	.6	79.0	.....	.....	
20.19	.13	.30	79.04	.....	.....	
2.2	2.8	1.7	79.7	1.1		Compare samples A-1, C-1, and A-2 for relation of point of sampling to composition. Note in A-1 lower methane content than put into ventilating current.
13.18	.12	.05	80.98	.....	.....	
18.67	.30	.55	79.06	.....	.....	

LECTED AT 1B-156.

11.64	1.36	.41	79.18	.93	.18	Considerable CO, CH ₄ , and H ₂ present, with high oxygen content.
1.80	1.13	.27	81.48	.71	.25	Oxygen low.
6.63	.59	.39	81.15	.....	.....	Time from tin-foil at 3R10.

DISCUSSION OF ANALYSES OF GAS SAMPLES.

The gases found in appreciable quantities in the various samples are as follows: Oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen (N_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), and hydrogen (H_2). The significance of the presence of each of these gases may be interpreted as follows:

The oxygen present may be from (1) incomplete combustion, (2) the aftergases mixing with air containing unconsumed oxygen, and (3) slight leakages of oxygen into the container after the sample was taken.

The carbon dioxide may be from (1) complete combustion of coal dust and of natural gas, when used, or (2) distillation of limestone in mixed dust tests.

The carbon monoxide may be from (1) combustion in the presence of an excess of glowing coal dust or coke, (2) distillation of coal, or (3) the reduction of water by hot carbon. The last source is indicated by the especially large proportion of carbon monoxide obtained in tests in which water has been mixed with or precipitated over the dust.

The nitrogen comes from the air. High percentages indicate that enough condensation of water vapor took place to offset the increased volume of gases due to the combustion of oxygen to CO , and to the distillation of gases. When the condensation has not been great enough to offset the increased volume of gases, low percentages of nitrogen result.

The methane and ethane may be from natural gas released into the mine before the test, or (2) the distillation of coal.

The ethylene comes from the distillation of coal.

The hydrogen may be from (1) distillation, or (2) the reduction of water with hot carbon, the latter action being indicated by samples from tests in which the dust had a high moisture content.

As either distillation or combustion may produce some of the gases, it is impossible to determine the part produced by one or the other. However, the presence of methane (except by prior introduction), some of the hydrogen, and ethylene is undoubtedly due to distillation.

One of the objectives in taking samples was to determine if possible whether distillation of gases preceded the direct contact of a dust particle with the flame. Some investigators have believed that a coal-dust particle burns as a whole, others that each dust particle distills gas through the radiant heat of the advancing flame, and that this gas, acting as tinder, ignites and causes the rapid combustion. It is conceivable that with freshly crushed coal a film of gas may be held on the surface of each particle by adsorption, thus fostering the distillation. In an attempt to determine this question, tin foil was

placed in the sampler circuit far enough in advance of the position of the sampler, allowing for lag, for the first of a group of samples to be taken immediately before the passage of the flame. Thus many of the foregoing samples, it will be noted in the first sampler (A-1 and C-1) obtained samples of nearly normal air. Thirty-one of these samples, including almost all of the first samples of each set containing over 19½ per cent oxygen with little carbon dioxide and little or no carbon monoxide showed a slight percentage of methane and one showed ethylene. This statement refers to samples in which no methane had been put into the mine air for test purposes; the mine itself producing no methane. The amount of methane in the 31 samples mentioned; that is, where no gas was used in the air current, varied from a trace to 0.1 per cent. In the sample containing 0.1 per cent (A-1, test 175), there was only a trace of carbon dioxide, no carbon monoxide, and 20.8 per cent oxygen. Though the amounts of distillate gases were small, their presence gave support to the idea of momentary predistillation. Succeeding samples in each case showed more extensive distillation, but such results were evidently due to the effects of combustion.

METHOD OF ANALYSIS.

By G. W. JONES.

The apparatus and methods used by the bureau for analysis of these gases are described in detail in Bulletin 42.²⁷ At present the bureau uses a modified Orsat apparatus, differing from the one described in Bulletin 42 in that the hydrogen and carbon monoxide are determined by combustion with copper oxide²⁸ heated in an electric furnace. This method has been found to give more accurate results than the older one, which used an ammoniacal cuprous-chloride solution for determining carbon monoxide and a sodium picrate solution of colloidal palladium for determining hydrogen. By the newer method the analysis can be made much more quickly.

The samples of gas are received at the laboratory in the usual glass containers of about 300 c. c. capacity. Immediately after the samples are taken the capillary neck of each container is sealed with a flame to prevent inward leakage of air or escape of gas.

The analyst uses the modified Orsat in starting an analysis because there is no way of telling whether the sample contains a high or low percentage of combustible. Before an analysis the train and capillaries are filled with nitrogen. The capillary of the gas sample is scratched with a file and the neck is broken off in a container under

²⁷ Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, pp. 78-90.

²⁸ Burrell, G. A., and Oberfell, G. G., The use of copper oxide for fractional combustion of hydrogen and carbon monoxide in gas mixtures: Jour. Ind. and Eng. Chem., vol. 8, 1916, pp. 231-237.

mercury. A gooseneck is inserted into the gas-sample bottle and a portion of the gas is drawn into the burette and discarded, as it is contaminated with the air in the gooseneck. A second portion is drawn into the burette and measured in the usual way. The carbon dioxide, unsaturated hydrocarbons, and oxygen are absorbed by potassium-hydroxide solution, fuming sulphuric acid, and alkaline pyrogallate solution, respectively, and the contraction noted in each. Then the gas is passed back and forth several times at a rate of about 10 c. c. per minute through the tube containing copper oxide, which is heated to 300° C. by an electric furnace, for the combustion of CO and H₂. After the copper-oxide tube has been cooled to room temperature with a blast of compressed air the gas is measured and the contraction, which is a measure of the H₂ content, is noted. Then the gas is passed into the potassium-hydroxide solution to remove the CO₂, and again measured, this contraction being equivalent to the CO content.

A measured volume of oxygen is next stored in the slow combustion pipette and the residual gas is fed in slowly from the burette. The slow-combustion pipette contains a platinum spiral heated to incandescence by an electric current; compressed air plays upon the hot pipette to prevent its getting too warm. Feeding the gas slowly into the oxygen permits the combustibles—methane and ethane—if present to burn as fast as they enter the pipette, and thus prevents any possibility of an explosion. If the gas contains only methane, the carbon-dioxide volume should equal one-half the contraction. If any ethane or higher hydrocarbons are present, the ratio is changed and the following formulas are used:

$$C_2H_6 = \frac{2CO_2 - \text{Contraction}}{1.5}$$

$$CH_4 = CO_2 - 2C_2H_6$$

In any event the total amount of paraffin hydrocarbons present equals $\frac{2 \times \text{Contraction} - CO_2}{3}$.

The contractions and volumes given for methane and ethane when divided by the volume of sample used and multiplied by 100 gives the percentages of the different constituents. The nitrogen is determined by difference.

All readings are made against a certain volume of gas in the compensator, whereby any change of temperature during an analysis does not affect the results. Each analysis is run in duplicate, and the results are accurate to within about 0.1 per cent.

If the gas contains a small percentage of combustible, it is transferred to the modified Haldane gas apparatus, described in detail in

Bulletin 42²⁰ and also in Technical Paper 31.²⁰ This apparatus in principle is essentially the same as the Orsat, but with it much greater accuracy can be obtained in analyzing samples having less than 1 per cent of combustibles. The burette has a capacity of 21 c. c., the bulb holding 15 c. c. and the graduated stem 6 c. c. Graduations are in 0.01 c. c., and by estimation can be read to 0.002 c. c. Analyses are checked to within 0.02 per cent.

A sample of gas is introduced into the burette and its volume measured; the CO₂ is determined by passing the gas into potassium-hydroxide solution and noting the contraction. The combustibles are then burned in the slow-combustion pipette with an incandescent platinum wire; after cooling the gas to room temperature the contraction is noted, and the CO₂ produced is absorbed in potassium hydroxide and its volume noted. The residual oxygen is absorbed in alkaline pyrogallate solution. An independent analysis of the gas is made for carbon dioxide and oxygen only. From these data the oxygen consumed in the combustion can be determined. Knowing the oxygen consumed, the contraction, and the carbon dioxide produced, the chemist can calculate the CO, CH₄, and H₂ from the following formulas:

$$\begin{aligned} H_2 &= \text{contraction} - O_2 \text{ consumed;} \\ CH_4 &= \frac{2 \times \text{contraction} - CO_2 - H_2}{3}; \\ CO &= CO_2 - CH_4. \end{aligned}$$

Small percentages of CO are checked qualitatively by a solution of palladium chloride, whereby any CO, if present, will precipitate metallic palladium.

If a gas contains no carbon monoxide by qualitative test, but the combustion data indicate its presence, the gas is investigated for ethane. If ethane is present, the oxygen consumed will have a larger value than the contraction, indicating a negative value for hydrogen. The amount of negative hydrogen indicated equals the amount of the ethane present. The ethane can also be figured from the general formulas for methane and ethane. In this way a double check on the ethane is obtained. The above line of reasoning assumes that if no carbon monoxide is present no hydrogen is present. If hydrogen is present the ethane value would be low and the methane correspondingly high.

In general, any gas with three combustibles can be determined by the modified Haldane apparatus. If more are present, a correct analysis is impossible and the results are figured as H₂, CO, and CH₄.

²⁰ Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, pp. 17 and 18.

²¹ Burrell, G. A., and Seibert, F. M., Apparatus for the exact analysis of flue gas: Tech. Paper 31, Bureau of Mines, 1913, p. 6.

DISCUSSION OF MORE IMPORTANT SAMPLES OBTAINED.

The following points of interest in connection with the analyses in Table 8 on page 112 may be mentioned:

1. The samples taken by the model A sampler at the time or after the passage of the flame frequently show considerable percentages of oxygen. Comparison of samples obtained in model A and model C types indicate that the higher oxygen content of the former is due to the sample being taken at the side of the entry, as shown in the samples collected in test 395. The model C sampler and the No. 1 bottle of the model A sampler both operated at the time of passage of the flame, the model C sampler being 0.03 second ahead. The gases in this C sampler showed nearly 9 per cent of carbon dioxide, whereas those in the model A sampler has less than 1 per cent. Other tests illustrating this feature are Nos. 368, 386, 389, 393, 394, and 486.

2. The distillation products—methane, ethylene, and hydrogen—begin to appear in the samples while the oxygen percentage still remains high. It has long been suspected that these products are distilled by the heat of the explosion ahead of the flame, and, being carried forward with the flame or a little ahead of it, assist materially in propagating the explosion. An attempt has been made to obtain samples that would give definite information on this matter; however, as there is no way of determining the exact instant at which the flame will arrive at any one particular point it is evident that such a sample can be obtained only by chance. Certain tests, however, have given evidence tending to confirm the suspicion mentioned. Sample 1 of test 175, taken one-fourth of a second before the flame, showed 0.1 per cent methane, 20.8 per cent oxygen, and only a trace of carbon dioxide. No gas had been used in this test. Sample 1 of test 111 B showed 0.15 per cent methane and 20.05 per cent oxygen. The sudden appearance of distillation products with the flame is well illustrated in test 292. Sample 1, taken just before the rupture of the tin-foil, contained 0.03 per cent methane and 0.01 per cent hydrogen. In sample 2, taken one-third of a second after the rupture, the methane had increased to 1.09 per cent and the hydrogen to 0.94 per cent. In test 350 a sample taken 0.2 second after the tin-foil was ruptured analyzed 1.18 per cent methane, 1.79 per cent hydrogen, and 11.63 per cent oxygen.

No conclusions can be based on such fragmentary evidence, but it is hoped that when the entire set of model C samplers is installed a set of samples taken at short intervals, beginning just ahead of the flame, can be obtained, which will show the presence or absence of distillation products ahead of the flame.

3. The ratio of CO to CO₂ and the relation of this ratio to the oxygen content varies greatly in the different samples. It is believed

that there is a more constant relation between this ratio and the percentage of oxygen than is shown by these analyses and that this relation will be indicated in samples taken at the center of the entry.

4. In tests with mixtures of dry dusts the presence of large percentages of carbon monoxide, sometimes exceeding that of the carbon dioxide—as in sample 2 of test 67, sample 2 of test 76, sample 3 of test 101, and sample 3 of test 126—probably indicates that a large excess of coal dust was present in the air current.

Later tests gave additional evidence that high percentages of carbon monoxide were probably due in part to excess dust in the air. In test 344 a sample analyzed 9.72 per cent carbon monoxide and only 0.37 per cent oxygen. Test 346 gave 5.93 per cent carbon monoxide, with only 1.29 per cent oxygen. Test 347 showed 11.66 per cent carbon monoxide, with 0.74 per cent oxygen. Other examples are tests 356, 358, 365, 404, 432, 441, and 488.

The samples collected in tests with mixtures of dust and water strongly indicate that the water is reduced by incandescent carbon, giving carbon monoxide and hydrogen. This reaction can be effected easily in the laboratory, and there is no reason why it should not occur in the mine.

As an illustration, consider test 333, having 25 per cent water in the dust. Sample 1 of the A sampler, taken just ahead of the flame, shows nearly normal air. Sample 2, taken just after the flame, gave 7.55 per cent carbon monoxide and 4.98 per cent hydrogen. The C sample, taken about 0.2 second later, shows 3.55 per cent carbon monoxide and 1.12 per cent hydrogen, indicating that these gases are rapidly removed, either by further combustion, by diffusion, or by absorption into the coal.

Practically the same thing is observed in test 334. Other illustrations are tests 342, 373, and 432.

5. The distillation products, including CH_4 , C_2H_4 , and H_2 , sometimes are present in large percentages. For instance, in test 101 the hydrogen content ranges from 3 to more than 5 per cent, and the total content of the three gases was 6.11, 8.35, and 5.63 per cent, respectively, in the three samples. This explosion was of medium strength, the maximum pressure at station E 950 being 20 pounds per square inch and the velocity of the flame about 750 feet per second.

Some excellent samples of distillation products were obtained in later tests, particularly in tests 344, 346, 347, 350, 356, 358, and 404.

Test 347 deserves special consideration. The explosion was extremely violent, giving the highest pressures ever recorded in the mine (see p. 517 and fig. 60). Only one sample was obtained, this being taken just after the passage of the flame. The sample showed 4.21 per cent methane, 6.16 per cent hydrogen, and 11.66 per cent carbon monoxide, the oxygen content being less than 1 per cent. It

is evident that if this mixture while hot came in contact with fresh air, as might happen if the hot gases burst through a stopping into another working place, a continuation of the explosion would ensue.

6. The sum of the percentages of CO_2 , O_2 , and CO is generally less than that of the percentage of oxygen in the original air. However, in test 67, sample 2, the sum is 21.23. It is probable that some of the CO_2 and CO may be due to distillation, as the presence of 3.71 per cent of CH_4 , C_2H_6 , and H_2 indicate considerable distillation.

7. The samples from tests 90 and 91 show high CO_2 content, especially sample 1, test 91. The sum of the CO_2 , O_2 , and CO in this sample is 21.49 per cent, which would account for 20.16 per cent of the original oxygen if it were the source of all the oxygen present. This is improbable, and it is believed that the high percentages of CO_2 in these tests were due to the presence of limestone dust at the end of the 300-foot coal-dust ignition zone. Limestone may have an additional merit over other imcombustible dusts for quenching an explosion due to its release of CO_2 and consequent dampening action.

8. In the latest tests in the butts and rooms the model C sampler was installed at the point 1B 156. The samples collected at this point do not differ from those collected in the entry. The results of three of them are included at the end of the table. It is expected that when future tests are made in the rooms a complete set of the model C samplers will be used in a manner similar to their use in the entry.

COKED DUST.

After each explosion test notes were made as to the position and the character of deposits of coked dust and other material. The results of the observations indicate that previous theories and opinions concerning the manner in which coked dust is deposited and interpretations from such deposits as to the movement of the flame of the explosion are of doubtful reliability. The main points of interest with reference to such deposits which seem to be established from the observations are as follows:

Coked dust is rarely found in the entries at places where great velocities were attained by the explosion. After explosions of pure Pittsburgh coal dust most of the heavy deposits are found within the first 300 feet from the origin during the time when the explosion is developing and the velocity is relatively low. Beyond this point the deposits become fewer and thinner, and finally none are found. It seems probable that the disappearance of coked dust deposits beyond this stage of the explosion is due either to the velocity of the gases being so great that any coke deposited is swept away as fast as it is formed, or to the high pressures prevailing at this stage of the explosion, making combustion so intense that the particles of

coal dust raised into the air are totally consumed, the combustion being aided by the carrying power of the high-velocity currents that sustains the particles until consumed.

POSITION OF COKED-DUST DEPOSITS.

In the main entry most of the coked dust has been deposited on the outby side of the rib and roof projections. The shelving posts and the nuts on the bolts holding the shelves in place seem to be particularly favorable positions for deposition. In those tests in which only small amounts of coke were deposited the coked dust was found as crusted coatings or isolated particles on only the upper part of the post—say $1\frac{1}{2}$ to 3 feet from the roof—whereas in the tests in which larger quantities of coked dust had been deposited thick-crusted coatings would be found on posts from the top almost to the bottom. Moreover, frequent batches of crusts or scales of coke were found on the outby side of projections of the ribs and roof. These coatings were usually in the form of ridges with rounded surfaces. A typical deposit on a half-inch projection from the roof would range in thickness from one-eighth inch at the edges to three-eighths or one-half inch at the middle of the deposit. Sometimes, however, when the coking was particularly heavy the coke would have a “quarter-round” section when removed; that is, with two plane sides where it touched the projection and the roof, the third side, or exposed surface, being rounded. Similar crusts were usually found on the outby sides of nuts of bolts fastening the posts to the ribs or the side shelves to the posts.

When coal dust was placed on cross shelves, more coke deposits were on the cross shelves than on the side posts. These deposits ranged from scattered coke bubbles, or globular coke, on the vertical sides of the shelves to thin sheets or crusts with the exposed surfaces convex. The crusts have a bright fused surface or a dull granular appearance; when the crust is broken, cellular coke is often found in the middle of the crust.

A curious difference in the position of the coke at corresponding positions in the entry and air course has been noted. For example, in test 115 (see fig. 20)²¹ the coke in the entry was almost entirely on the outby side, whereas that in the air course was on the inby side of the projections. This deposition was also true of test 80 (see fig. 21). The difference has prevailed in practically all tests, and there is considerable uncertainty as to the reason. In these particular tests the zones in the two entries were exactly the same, except that

²¹ The triangular symbol used in figure 20 and similar figures indicates the position of coked dust with special reference to its inby or outby position on projections. The base of the triangle represents the vertical plane of attachment of the coke to a timber or a projection of the rib or roof; the apex of the triangle indicates the free vertical surface, and points inby or outby according to whether the deposit was on the inby or outby side of the projection.

the air course had two butt entries (at A 850 and A 900), one of which had four rooms turned off it, and the main entry had only a single butt (at E 775) 100 feet long, with no rooms turned from it.

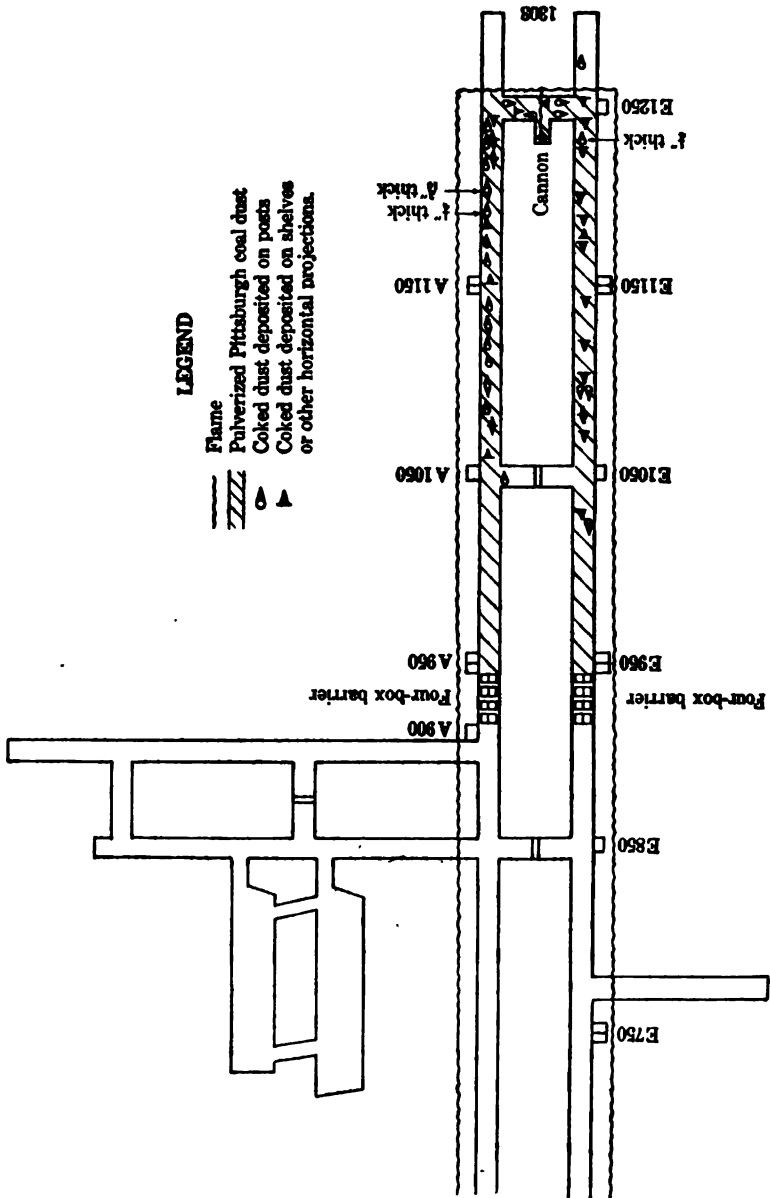


FIGURE 20.—Diagram showing position of coked-dust deposits formed in test 113.

These butt entries and rooms offered opportunity for release of pressure and reduced the resistance to the advance of the explosion. Consequently greater velocities and quicker reduction of pressures

in the air course usually resulted, with correspondingly quicker setting up of return waves and of reversed air currents. It may be

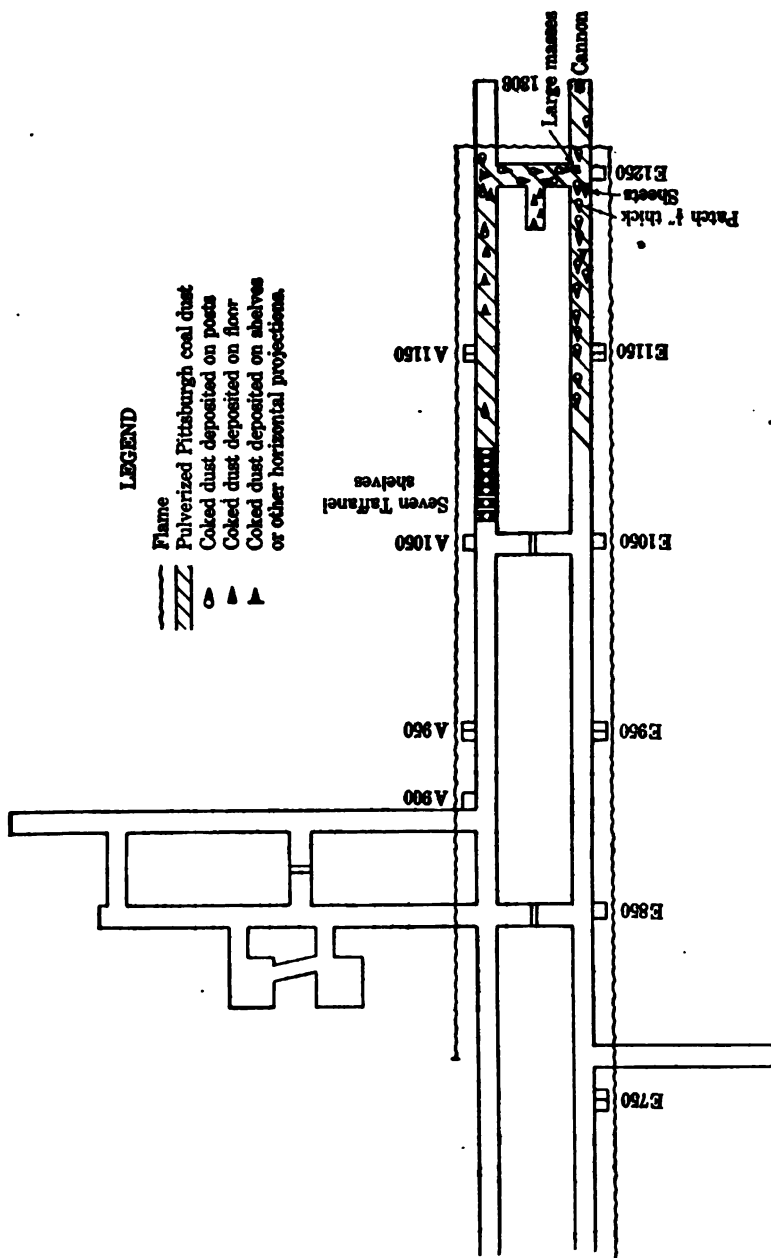


FIGURE 21.—Diagram showing position of coked-dust deposits formed in test 80.

that the reversal of the air current in this entry had something to do with the different location of the coked-dust deposits.

TEST 195.

In test 195 (see fig. 22) the coke deposition in the air course was also on the inby exposures, but in the zone between stations A 1050 and A 950 there were double deposits of coked dust; that is, two successive deposits on the inby sides of the cross shelves.

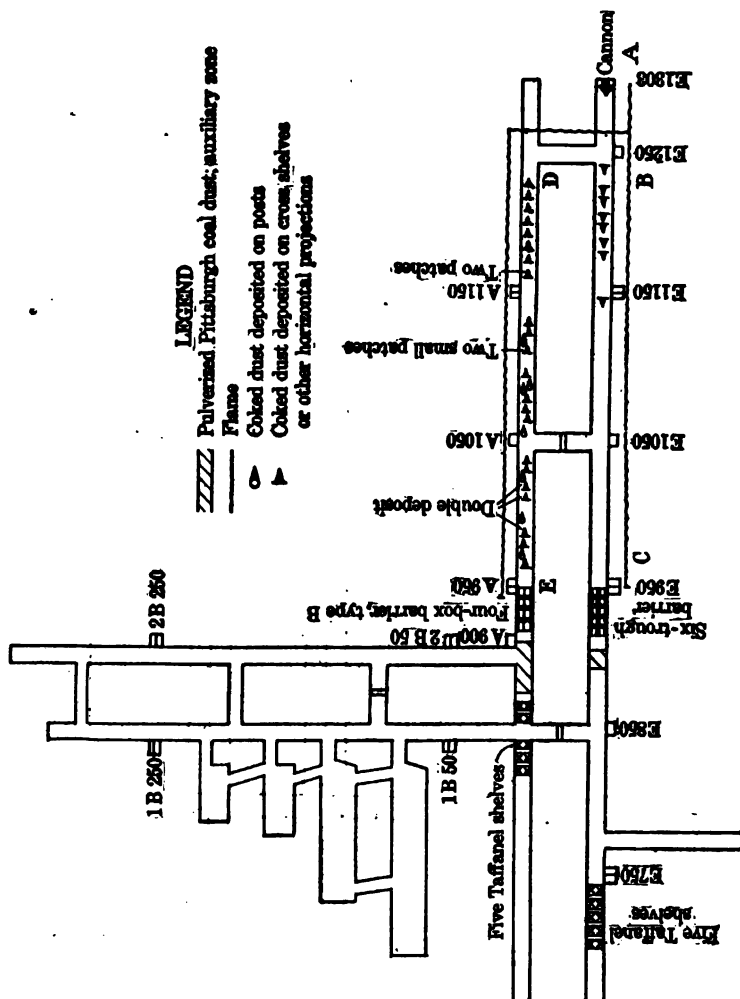


FIGURE 21.—Diagram showing position of coked-dust deposits formed in test 198 A to C, B to D, and D to E laden with mixed dust, 80 per cent Lower Kifanning coal and 20 per cent shale.

These deposits may be readily distinguished by the overlapping of the layers and by the parting line between them when the coke is broken off.

The air-motion vane at station A 950 showed two reversals of the air current before the explosion reached it. As this test is the only one in which such a condition occurred, and the only one in which double deposition of coke dust was noted, the two phenomena may be related.

Because of the uncertainty as to the manner in which coke dust is deposited in relation to the path of an explosion observation of the deposits with a view to fixing the point of origin is of doubtful value.

TEST 105.

Test 105 (see fig. 23) illustrates the difficulty of using the position of the coke deposits to locate the origin. In this test the coal-dust distribution extended for 500 feet from the faces of the main entry and of the parallel air course. The flame of the explosion extended through both coal-dust zones to the barriers at the ends of the respective zones. It also penetrated the butt entries off the air course which were unguarded by barriers. Although no coal dust had been distributed in the butt entries, evidently enough dust was carried in, together with what had previously accumulated, to continue the explosion through the butt entries and the rooms off the first butt. Figure 23 shows the position of the principal coke deposits on timbers and projections with reference to the direction in which the coke deposits faced. Details of the coke deposits and notes on other manifestations of the explosion are given in the report on page 131.

An investigator attempting to fix the origin of this explosion from the position of the coked dust would find on entering the main entry that all the principal coking in by the extinguishing barrier at station 800 was on the outby facings, this position on timbers and projections continuing to the last cut-through. Here he would find some coke facing the air course, but other coke deposits facing the entry. In going out of the air course he would find that practically all the coke was deposited on the inby faces. On entering the second butt he would find deposits of coke facing inby, and in the last cut-through deposits facing toward the first butt. In the first butt and the rooms turned off from it he would find facings both inby and outby. Investigators of explosions have generally concluded that after an explosion is well under way the coke is found chiefly on the reverse side from the direction the explosion approaches.^{11a} If this conclusion were invariably true and other manifestations of the explosion were disregarded, the investigator of this test explosion would have been led to the conclusion that it originated in the rooms of the first butt entry rather than actually at the face of the main entry.

OTHER OBSERVATIONS ON POSITIONS OF COKE DUST.

In many tests where the origin of the explosion was in the face of the main entry coke dust has been found on the inby sides of pro-

^{11a} This view has had support from drift or slope mine explosions; where the explosion flame extended into open air, coke has often been found on the sides of timbers and posts that face away from the mine mouth.

jections that were only a short distance in by the rock-dust barriers, although coke deposits in other parts of the entry were all on the

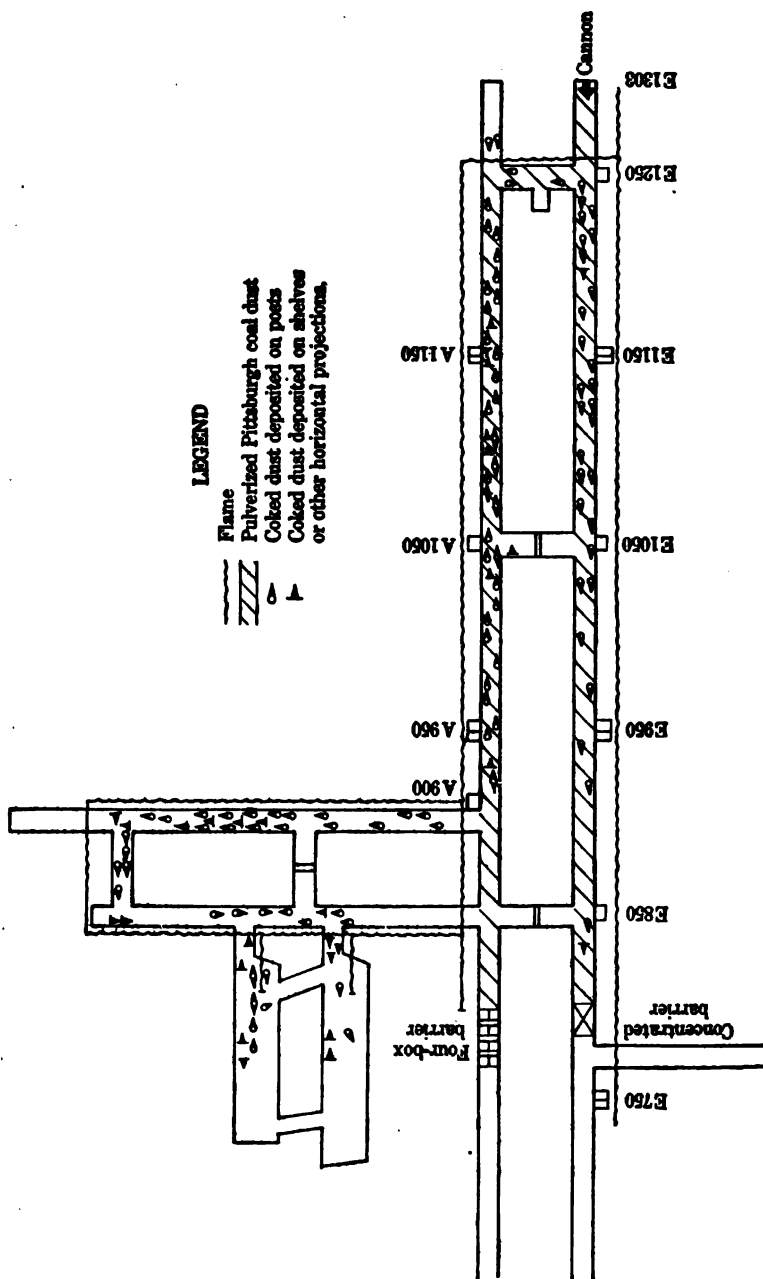


FIGURE 23.—Diagram showing position of coked-dust deposits after test 103.

outby-facing surfaces. One suggested cause for this difference is that the barriers operate before the flame of the explosion arrives,

and the resistance of the dropping mass of rock dust and containers momentarily checks the velocity of the gases, permitting the deposition of coke on the facing exposures. Another suggestion, and perhaps a more logical one, is that generally the explosion wave has not culminated until it has reached the barrier; then a retonation wave, or waves, starts back toward the origin, passing through still burning dust and causing deposits of coke on the reverse surface of exposures.

CHARACTER OF COKE DUST.

In Bulletin 20²² the character of coke and of dust found after mine explosions is discussed in detail. The observations made therein are in general confirmed by the observations after explosions in the experimental mine, due allowance being made for the differences that obtain in extensive workings in large industrial mines. The principal kinds of coke dust found after tests at the experimental mine are as follows:

1. Bright coke crusts, generally found on the reverse side of timbers and projections, indicating a high degree of temperature and that the molten coke had been deposited on the back exposures by eddies, the burning coal dust evidently having been carried along by the explosion gases.

2. Loosely adhering, coked or partly coked, preformed dust deposits, which may or may not have a surface crust. This type is formed when the explosion has not been violent, and evidently the dust is coked while in place.

3. Individual particles or globules of coke, evidently thrown while molten against projecting surfaces, where they stuck and were not carried away by subsequent scouring with gases.

4. Particles of coke that have been loosely thrown into crevices and recesses or, when an explosion was dying away, upon fronting exposures.

5. Minute globules of coke, some of which are round and have a cellular interior, generally found on the floor of the entry. These small particles have evidently assumed this form while being carried along in the cooling afterdamp and have dropped to the ground, where they have rolled along until striking against projections such as track ties and rails.

6. Coke formed in situ, where the surface of the coal rib or coal roof indicates blistering and thin layers of the coal have been coked.²³ Plates X and XI in Bulletin 56, on the first series of explosion tests, illustrate such formations.

This type of coke is usually found only in dead ends and rooms where the flame has lingered. It is most likely to be found where there is some methane.

²² Rice, G. S., and others, *The explosibility of coal dust*: Bull. 20, Bureau of Mines, 1911, pp. 106-115.

²³ Rice, G. S., and others, *First series of explosion tests in the experimental mine*: Bull. 56, Bureau of Mines, 1913, p. 75.

In the dead ends of the entries and rooms much soot is found coating all surfaces, as described on page 75 of Bulletin 56. After all explosions unburned coal dust is found in more or less thick layers, sometimes on the fronting, sometimes on the reverse exposures and not infrequently covering the coke crusts. In the vicinity of the rock-dust barriers there is often a coating of rock dust. The deposition of such unburned and incombustible dust is, however, a manifestation of the later movements of the gases and air in establishing an equilibrium after the explosion and can not be regarded as of consequence in tracing the source of an explosion. In the investigation of explosion disasters in mines the indications from such dust have proved too complicated to be useful.

Many analyses have been made both of coke dust from the tests at the experimental mine and from explosions in active coal mines, a typical analysis being given on page 112 in Bulletin 20. Table 9 gives the analyses of a large number of coked-dust samples collected in the experimental mine, together with the analysis of the various coals from which the coked dusts were formed.

TABLE 9.—Results of analyses of samples of coked dust.

Test No.	Percent of rock dust in loading.	Position of sample.	Analysis.				Ratio V. (V.+ F. C.)	Original ratio, and remarks.
			Moist-ure.	Volatile matter.	Fixed carbon.	Ash.		
			Average of analyses of Pittsburgh coal.					
			1.85	36.43	54.68	7.04	39.98	
			Analyses of coked dust from Pittsburgh coal.					
27	0	E 1075	2.63	21.15	57.27	18.95	26.97	40.0
27	0	E 1150	3.70	19.75	63.27	13.28	23.79	
27	0	E 1250	2.85	19.10	66.82	11.23	22.23	
30	0	E 1200	3.15	18.13	58.84	19.88	23.56	
31	0	E 1150	2.58	25.72	58.30	13.40	30.61	
31	0	E 1150	2.35	24.90	54.57	18.18	31.33	Flakes of coke from edge of dust deposit.
31	0	E 1250	3.15	15.90	64.97	15.98	19.66	
32	0	E 1250	3.38	18.70	61.99	15.93	23.17	
32	0	E 1150	2.68	21.37	58.35	17.60	26.81	
45	0	E 965	2.58	16.73	50.14	30.55	25.01	
45	0	C 10	2.03	14.53	46.34	37.10	23.87	
49	0	E 1040	1.63	34.43	55.94	8.00	38.10	
49	0	E 1075	1.95	21.41	62.49	14.15	25.52	
51	0	E 1120	1.60	20.75	57.36	20.29	26.57	
58	0	E 1075	2.51	21.53	49.45	26.51	30.32	
59	50	E 1075	1.76	21.65	48.05	28.54	31.06	
61	0	E 1075	2.18	23.86	51.60	22.36	31.62	
61	0	E 900	2.28	15.46	49.55	32.71	23.78	
72	50	E 1150	1.77	24.73	46.21	27.29	34.57	
73	50	E 985	1.65	35.30	29.24	33.61	54.69	
73	50	E 1210	1.86	21.06	50.75	26.31	29.33	
73	50	E 1075	1.93	22.96	45.68	20.41	33.47	
73	50	E 1150	2.40	24.94	46.83	25.83	24.75	
73	50	E 925	1.57	23.47	46.02	26.94	33.78	
74	40	E 1075	1.77	22.54	45.77	29.92	33.00	

TABLE 9.—Results of analyses of samples of coked dust—Continued.

Test No.	Percent of rock dust in loading.	Position of sample.	Analysis.				Ratio V. (V.+F.C.)	Original ratio, and remarks.
			Moist- ure.	Volatile matter.	Fixed carbon.	Ash.		
			Analyses of coked dust from Pittsburgh coal—Continued.					
74	40	E 750.....	1.64	23.99	42.38	31.99	26.14	Coke bubbles or dust.
74	40	Floor, E 1300.....	1.83	24.88	27.50	45.79	47.49	
74	40	E 1245.....	3.48	17.84	51.72	26.96	26.64	Coke bubbles.
75	40	E 1007.....	6.56	20.39	40.05	33.00	33.74	
75	40	E 1075.....	1.69	21.77	43.18	33.36	33.51	
81	0	A 1250.....	1.27	15.30	56.91	26.52	21.19	Coke globules.
88	0	A 1241.....	.62	21.03	52.83	25.52	26.47	
89	0	E 1205.....	1.94	17.01	60.24	20.81	22.02	
105	0	1-B-104.....	2.56	18.14	45.16	34.14	28.66	
107	50	A 1095.....	2.41	23.27	47.92	25.40	32.68	
109	50	E 1074.....	2.59	20.61	56.24	20.56	26.82	
110	70	Floor, E 1000.....	4.49	14.05	21.32	60.14	39.72	
133	60	Floor, E 1250.....	13.04	25.25	20.87	40.84	54.76	
143	50	A 1070-A 950.....	1.71	17.38	22.35	58.56	43.74	
183	80	Floor, E 1235.....	1.29	15.46	47.54	35.71	24.54	
185	77	Platform, E 1300.....	2.03	28.26	58.89	10.82	32.42	22.13.
252	30	Dashpot, E 950.....	2.01	28.25	38.28	31.46	42.46	
272	50	A 1200-A 1100.....	0.95	18.95	46.63	33.47	28.89	
275	50	Coke trap before disk.....	1.48	19.29	28.81	50.42	40.10	
275	50	Coke trap after disk.....	1.88	26.89	34.97	36.26	43.48	
275	50	Before disk at E 952.....	.93	21.17	27.20	50.70	43.77	
277	50	Coke trap before disk.....	1.52	27.82	37.72	32.94	42.45	
277	50	Coke trap after disk.....	1.13	21.97	36.95	39.95	37.29	
Average of analyses of Fire Creek coal.			1.00	20.27	71.34	7.39	22.13	
Analyses of coked dust from Fire Creek coal.			3.60	10.42	69.22	16.76	13.09	
237	0	E 1074-E 1154.....	3.60	10.42	69.22	16.76	13.09	
237	0	A 950.....	3.06	11.10	67.76	18.08	14.08	
239	50	Entry, C-S.....	.77	7.83	33.40	58.00	18.99	
Average of analyses of Beckley bed coal.			.86	18.20	72.37	8.57	20.09	
Analyses of coked dust from Beckley bed coal.			1.77	11.66	60.74	25.88	16.10	
126	0	E 1219.....	1.77	11.66	60.74	25.88	16.10	
126	0	E 994.....	1.23	13.52	52.64	32.61	20.44	
126	0	E 1015.....	1.23	12.85	54.99	30.93	18.94	
126	0	E 1175.....	1.78	10.81	61.93	25.48	14.87	
126	0	C-85.....	1.15	12.47	66.17	20.21	15.85	
132	40	A 1233.....	1.71	8.98	47.25	42.06	15.98	
Average of analyses of Lykens Valley coal.			1.03	8.47	76.98	13.52	9.91	
Analyses of coked dust from Lykens Valley coal after explosion test.			2.22	10.42	73.16	14.20	12.47	
135	0	E 1250.....	2.22	10.42	73.16	14.20	12.47	
135	0	Platform, E 1300.....	3.25	9.28	66.47	21.00	12.25	

In general coked dust shows only partial coking of the coal matter. A great deal of the finest dust is evidently consumed completely and it is only the coarser particles that make coke crusts.

In tests where the coal dust is mixed with shale or with limestone dust the proportion of coke is much less and the coke is friable, whereas in a mixture containing as much as one-half shale or rock dust little or no coke is formed.

POSITION OF COKE DUST WITH REFERENCE TO DIRECTION OF EXPLOSION.

Foreign investigators, Atkinson ³⁴ and others, have generally held the opinion that coke dust is found on the reverse side of timbers from the direction of the explosion. The senior author, in investigations of large mine explosions, has also observed that the coke is usually on the reverse side, except near the origin and terminals of the explosion flame. His views, given in Bulletin 20,³⁵ are here abstracted:

* * * At the originating point of a coal-dust explosion, and near-by, the coked particles are projected directly upon the exposed surfaces of props, caps, collars, and walls, particularly upon the upper portions toward the roof. In other words, the coked dust faces the originating point. * * * Near the point of origin, on the reverse side of props or collars (facing away from the source of explosion), there are usually only a few scattered particles of coke. * * * After the explosive wave has passed from the room into the entry, or, if it originated in the entry, has travelled along it a few hundred feet, it gathers headway, and, provided it still has enough dry and pure coal dust to feed upon, forms thinner and more scattered coke scales. As the velocity of the explosive wave increases it no longer deposits coked dust on the facing side of props or posts, collars, and rib projections, except occasionally as scattered particles, but forms thin scales, often bright, first on the underside of collars, where there are any, then on the reverse side of timbers or projections. At this stage coke particles may be driven into facing crevices in the ribs or cracks in timbers. * * * *

As the explosive wave gains in velocity practically no coke is deposited in the main passageway traversed, and is then to be looked for in isolated splashes on the lee side of corners of crosscuts or other side openings on the coal rib or on timbers in these openings.

* * * The coked dust is sometimes located on the facing side in very wide places, as in wide rooms, where the velocity of the wave becomes less, from opportunity to spread laterally.

The fact that coke is not deposited where the sweep of the explosive wave is greatest is possibly accounted for by the extreme speed attained, which carries along everything loose. This action is shown by the scouring of the walls of the passageway.

The records of coke deposition, obtained in experiments made in the experimental mine, show inconsistencies that have not been fully explained. In the main entry, when the explosion has originated in the face, the coked dust is principally on the reverse surfaces, whereas in the air course coke is often found on both the facing and reverse surfaces, and at other times on only the surfaces facing the explosion. Therefore, as before stated, it is not possible to trace the direction of an explosion to an unknown origin by observations of the coke dust alone. Such evidence must be correlated with other manifestations of heat and violence.

³⁴ Atkinson, W. N., and Henshaw, A. M. The investigation of colliery explosions, December, 1909.

³⁵ Rice, G. S., and others. The explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, pp. 110-112.

CHAPTER IV.—TESTS WITH PITTSBURGH COAL DUST AND VARIOUS INCOMBUSTIBLE DUSTS.

GENERAL CHARACTER OF THE TESTS.

Many tests were made with mixtures of Pittsburgh coal dust and various incombustible dusts in order to determine the effects of various test conditions before adopting standardized conditions for testing different coals and the relative efficiency of the different rock dusts in preventing or limiting explosions.

The earlier tests of the second series had to do with the development of explosions of Pittsburgh coal dust in the enlarged mine and with the effort so to control the methods of igniting and placing the dust that under repetitions of any given conditions of test the explosion could be essentially duplicated as regards velocity of flame and pressure waves. There are so many variables that numerous tests of different methods were required in order to accomplish this result, the fundamental difficulty being to reproduce dust clouds of equal density.

After this duplication had been accomplished within reasonable limits the next step was so to standardize the testing that other kinds of coal dust from typical mines of the country could be tested for explosibility in comparison with the Pittsburgh coal dust used at the experimental mine.

In these tests it was necessary to use smaller quantities of coal dust, in order to keep down the costs of shipping the samples to the mine but the test zone had to be long enough to insure that the test would be practical in character and representative of an explosion in the typical coal mine.

In selecting a suitable length for such a test zone the ordinary length of a mine room was taken as a measure. Another practical consideration was that in making tests of pure coal dusts of high explosibility the explosion should be so controlled that the damage to the mine arrangements would not be so great as seriously to delay testing work or necessitate expensive repairs. It had been demonstrated already by previous testing that rock-dust barriers of the Taffanel type and the improved barriers designed by the Bureau of Mines would effectively extinguish the flame of even violent explosions. Therefore it was planned to place such barriers at the end of the test zone in the entry and in the air course, respectively.

These considerations led to the adoption of a test-zone length of 350 feet, including an ignition zone of 50 feet. Moreover, in test,

104 and in those following, double-entry loading was adopted to provide two nearly symmetrical branches for the explosion to traverse from the 50-foot ignition zone, the entry branch being 300 feet long and the air-course branch of the same length, plus the cut-through of 50 feet.

An important improvement with a view to getting uniform dust clouds was the use of cross shelves for loading part of the dust to be tested, as previously discussed. This arrangement was first used in test 115 and was thereafter employed in the test zones beyond the ignition zone.

Another important improvement was lining the test zones in both entries and the crosscut with a cement mixture, thus permitting easier cleaning and preventing contamination of the coal dust under test with coal dust from the walls and from the roadbed of the entries. The lining had been finished in the main entry for test 140 and was completed in the air course for test 146.

As explained in detail hereinafter in the description of "standard test methods" (p. 179), the tests of different coal dusts are of two kinds, called ignition tests and propagation tests, respectively.

An ignition test is one in which the dust or mixed dust is tested as to whether it will be ignited enough by a standardized blow-out shot to carry the explosion through the 350-foot test zone.

A propagation test is one in which the dust or mixed dust is tested as to whether it will be ignited by the preliminary explosion of a 50-foot zone of pure Pittsburgh dust, simulating an explosion from ignition of untreated coal dust at the face of a mine entry or the ignition of a large pocket or body of fire damp. In addition to determining the ignition and propagation limits of the dust under test in pure air, supplementary tests are made with small percentages of natural gas in the air current in order to determine to what extent the explosibility limits of the dust are changed by the presence of small proportions of inflammable gas in the mine air.

Three series of ignition tests with pulverized Pittsburgh coal dust were made. One series utilized limestone dust such as is ordinarily sold to farmers for spreading on poor or acid soils; another dust made from "roof shale" taken from above the Pittsburgh coal, and the third series was with dust made from a so-called "pit shale" which has a very low content of combustible and was mined from a short drift in the side of the valley. This shale is 62 feet below the level of the Pittsburgh coal bed at the experimental mine. Three kinds of propagation tests were tried. The first arrangement had a 100-foot starting zone of pure coal dust, and the mixed dust was spread for various distances beyond, usually 500 feet. This arrangement did not seem to give a strong enough starting impulse, the reason being, as later demonstrated, that no dust was distributed in

the cut-through and in the air course, so some tests were made with a 300-foot starting zone of pure coal dust. The dust zone was still confined to a single entry, but while the starting impulse was strong enough to overcome the effect of the dustless cut-through in this arrangement, in many tests the results were erratic.

Later, coal dust was distributed in the cut-through and air course. When this was done, a 50-foot initiating zone of pure coal dust gave practically as strong a starting impulse as the 300-foot zone used in the previous tests; also the results were more consistent, besides giving a check on propagation in the air course; hence this arrangement was adopted as standard for propagation tests of different coal dusts.

Explosibility tests were made with pulverized coal dust and various incombustible materials as follows:

Ignition tests:

- (1) With mixtures of limestone dust and coal dust,
- (2) With mixtures of roof-shale dust and coal dust,
- (3) With mixtures of pit-shale dust and coal dust.

Propagation tests:

- (1) 100-foot starting zone of pure Pittsburgh coal dust—
 - (a) Mixtures of limestone dust and coal dust,
 - (b) Mixtures of roof-shale dust and coal dust;
- (2) 300-foot starting zone—
 - (a) Mixtures of roof-shale dust and coal dust,
 - (b) Mixtures of limestone dust and coal dust;
- (3) 50-foot starting zone, with double-entry distribution of dust—

Mixtures of roof-shale dust and coal dust,

Mixtures of pit-shale dust and coal dust.

ANALYSIS AND SIZE OF COAL DUST USED.

The average of the proximate analyses of a large number of samples of Pittsburgh coal dust used in these explosibility tests was as follows:

Average composition of Pittsburgh coal dust used in tests.

	Per cent.
Moisture.....	1.85
Volatile matter.....	36.43
Fixed carbon.....	54.68
Ash.....	7.04
Average ratio of volatile combustible to total combustible, 40.	

The averages obtained in sizing tests of a large number of samples of pulverized Pittsburgh coal are as follows:

Cumulative percentages in sizing tests of pulverized Pittsburgh coal.

	Per cent.
Through 100-mesh screen.....	99.3
Through 200-mesh screen.....	87.2
Through 240-mesh screen.....	81.0

IGNITION TESTS.

PITTSBURGH COAL DUST AND LIMESTONE DUST.

Five tests were made in which Pittsburgh coal dust and limestone dust were mixed.

COMPOSITION AND FINENESS OF THE LIMESTONE DUST.

The results of an analysis and screen tests made on the limestone dust used in the series are shown in the table following. The ground limestone was the same as the material sold to farmers in the Pittsburgh district for agricultural purposes. In 1914 the limestone dust cost \$2.65 per ton delivered at the experimental mine, exclusive of the cost of bags.

Results of analysis of the limestone dust.

	Per cent.
Moisture.....	0.57
Carbon dioxide.....	31.61
Organic hydrogen.....	.17
Organic carbon.....	.62
Sulphur.....	1.24
Sulphur trioxide.....	.16
Silica.....	15.71
Alumina.....	4.74
Iron oxide.....	2.73
Calcium oxide.....	39.37
Magnesium oxide.....	.88
	97.74

Results of screen test of the limestone dust, in cumulative percentages.

	Per cent.
Through 20-mesh.....	100
Through 100-mesh.....	72
Through 200-mesh (screen A) ^a	56
Through 240-mesh.....	52

COMPOSITION AND FINENESS OF COAL DUST.

The average analysis of the coal dust and average screen test for the series was as follows:

Average composition and fineness of the coal dust used in ignition series.

SCREEN TEST.		PROXIMATE ANALYSIS.	
	Cumulative percentage.		Per cent.
Through 100-mesh.....	100	Moisture.....	1.71
Through 200-mesh (screen A).....	89	Volatile matter.....	35.50
Through 240-mesh.....	79	Fixed carbon.....	54.25
		Ash.....	8.54
			100.00

^a In the tests at the experimental mine three types of 200-mesh screen were used, designated A, B, and C, respectively. Screen A, used in the earlier tests, had holes slightly larger than standard size; screen B had holes too small; screen C, obtained later, was of the correct size.

RESULTS OF THE TESTS AND DISCUSSION OF THE RESULTS.

Table 10 shows the more important data of the tests. The coal dust was distributed at a rate corresponding to 2 pounds per linear foot of entry. The fourth column of the table gives the percentage of incombustible in the mixture as obtained by adding the percentage of limestone dust and percentages of ash and moisture in the coal as shown by proximate analysis.

TABLE 10.—*Ignition tests with mixtures of pulverized Pittsburgh coal dust and limestone dust.*
 [Originating cause: Standard blown outshot from cannon at station E 1300.]

Test No.	Date.	Mixed dust.		Instrument records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocities between stations.						Length of flame in mixed-dust zone.	Ignition obtained.
		Ratio of coal dust to lime-stone dust in mixture.	Incom-bustible lime-stone plus mixture and ash of coal.		Sta-tion 1150.	Sta-tion 980.	Fall at station 1250.	Veloc-ity.	Fall at station 1150.	Veloc-ity.	Fall at station 1050.	Veloc-ity.	Fall at station 980.	
75	1914. Jan. 23	80:40	Per ct. 46.2	E 1300 to E 900, 400 feet at 24 pounds per foot..... Platform.....	Lbs. per sq. in. (e) (e)	Lbs. per sq. in. (e) (e)	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Yes.
				1,332 83	(e) (e)	(e) (e)	.....	.....	1.678	.....	.....	121	3.327	Fed. (b)
70	Jan. 13	50:50	55.1	E 1300 to E 700, 600 feet at 4 pounds per foot..... Platform.....	(e) (e)	(e) (e)	.....	.....	.....	.....	.....	.....	.....	125 } 75 } No.
				2,400 100	(e) (e)	(e) (e)	.....	.....	.....	.....	.....	.....	.....	
119	June 2	50:50	55.1	E 1300 to E 950 (350 feet) and E 1250 to A 950 (350 feet), 700 feet at 4 pounds per foot..... Platform.....	7 9	8 7	1.692	100	2.218 1.933	310 282	2.541 2.337	289 297	2.813 2.673	Yes. ^c (b)
				2,800 25	.....	.....	.....	.....	.....	.....	.....	.....	.....	
128	June 30	40:60	64.1	E 1300 to E 950 (350 feet) and E 1250 to A 950 (350 feet), 700 feet at 5 pounds per foot..... Platform.....	1 1	0 0	2.021 .....	.....	.....	.....	.....	.....	.....	100 } 75 } No.
				3,500 25	.....	.....	.....	.....	.....	.....	.....	.....	.....	
128-B	June 30	40:60	64.1	Dust remaining from test 128. Fresh dust on platform.....	1 1	0 0	1.706	20	6.678	.....	.....	.....	.....	125 } 75 } No.
				50	.....	.....	.....	.....	.....	.....	.....	.....	.....	

^a No pressure registered.

^b Flame extended through zone.

^c With double-entry loading and dust on cross shelves.

^d Exact quantity not known.

In test 70 the mixed dust (50 per cent coal dust and 50 per cent limestone dust) was distributed on side shelves in the main entry only, for a length of 600 feet, at the rate of 4 pounds of mixed dust per foot. With this arrangement no ignition was obtained. Ignition was obtained with a similar zone in test 75, when the percentage of limestone dust had been reduced from 50 to 40 per cent. When the transverse shelves were installed, test 119 was made with the same mixture of coal dust and limestone dust as was used in test 70, the dust being distributed in both entries on cross shelves and side shelves out to stations E 950 and A 950. With this arrangement ignition was obtained, pressures of 7 to 9 pounds being registered at the various stations. After ignition was obtained with the mixture of 50 per cent coal dust and 50 per cent limestone dust tests 133 and 133B were made to determine the possibility of obtaining ignition with a mixture of 40 per cent coal dust and 60 per cent limestone dust under the same conditions of dust distribution. No ignition was obtained in either test.

The results of these tests showed that ignition could be obtained through a mixture of limestone and coal dust in which the incombustible content was 55.1 per cent, but could not be obtained in one in which the incombustible content was 64.1 per cent.

SERIES WITH MIXTURES OF PITTSBURGH COAL DUST AND ROOF-SHALE DUST.

Three tests were made with mixtures of coal dust and roof shale. In all three tests the igniting shot was from the cannon at station E 1300 and the explosion zone extended outby in both the entry and the air course to station 950.

The pulverized shale dust used in these tests was made from "draw slate" collected in the rooms of the experimental mine. The average of a number of ultimate analyses of samples of roof-shale dust used in these and other tests shows a combustible content of organic carbon and hydrogen of about 9 per cent, whereas the proximate analyses of the shale showed an apparent combustible content (sum of the volatile matter plus fixed carbon) of about 15 per cent, giving a ratio of 3 to 5. Therefore for those mixtures of which a proximate analysis only was obtained, three-fifths of the combustible (volatile matter plus fixed carbon) in the shale was taken as the percentage to be used in calculating the combustible content of the mixture.

RESULTS OF TESTS.

TABLE 11.—*Standard ignition tests with mixtures of pulverized Pittsburgh coal dust and pulverized roof-shale dust.*

[Originating cause: Standard blowout shot from cannon at station E 1300. Zone: Standard test zone from stations E 1300 to E 950, and from stations E 1250 to A 950; total length 700 feet.]

Test No.	Date (1914).	Mixed dust.				Instrument records obtained in entry or air course.	Maximum pressure.	
		Ratio of coal dust to shale dust in mixture.	Calculated content of incombustible.	Distribution and rate of loading and total amount of dust.			Station 1150.	Station 950.
116	May 26	50 : 50	Per. ct. 49.8	Zone, 4 pounds per foot. Pounds. 2,900 Bench. 25		Entry. Air course.	Lbs. per sq. ft. 27 23	Lbs. per sq. ft. 20 24
117	May 27	40 : 60	58.2	Zone, 5 pounds per foot. 3,500 Bench. 25		Entry. Air course.	9 12	8 11
146	Dec. 1	40 : 60	58.9	Zone, 5 pounds per foot. 3,500 Bench. 25		Entry. Air course.		
				3,525				

Test No.	Instrument records obtained in entry or air course.	Time of tin-foil rupture at stations and flame velocities between stations.						Length of flame in mixed-dust zone.	Ignition obtained.
		Foil at station 1250.	Velocity.	Foil at station 1150.	Velocity.	Foil at station 1050.	Velocity.			Foil at station 950.
		Seconds.	Feet per second.	Seconds.	Feet per second.	Seconds.	Feet per second.	Seconds.	
116	Entry.			1.232	602	1.458			(a) Yes.
117	Air course.			1.308	690	1.453			
117	Entry.	1.800	420	2.038					(a) Yes.
146	Air course.								
	Entry.								25 No. ^b
	Air course.								

^a Flames extended through zones.^b Entries were concreted lined.

Table 11 presents the principal data with reference to the standard ignition tests using roof-shale dust. The fourth column gives the incombustible content of the mixture of roof shale and coal, which is obtained as follows: The analysis of the mixed dust is reported in percentages of three constituents—moisture, moisture-free coal, and moisture-free shale. The percentage of coal in the mixture is multiplied by the percentage of ash in the coal (moisture-free basis) obtained from samples of pure coal dust taken before the mixture was made up; the percentage of shale in the mixture is multiplied by the percentage of incombustible in the shale (found as described above) obtained from samples of the pure shale taken before mixing.

The sum of these products plus the moisture as obtained from the mixed dust gives the percentage of incombustible in the mixture. The following illustrates the method:

Results of moisture determinations for mixture used in test 146.

Mixed-dust sample.	Moisture.	Coal (moisture free).	Shale (moisture free).
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
20811.....	2.1	58.9	59.0
20812.....	2.2	59.2	58.6
Average.....	2.15	59.05	58.8

The content of incombustible in the unmixed coal sample was 7.98 per cent (moisture free).

$0.3905 \times 0.0798 = 0.0312$ gram., or 3.12 per cent, incombustible in the mixture due to the coal.

The content of incombustible in the unmixed shale sample was 91.2 per cent (moisture free).

$0.588 \times 0.912 = 0.536$ gram, or 53.6 per cent, incombustible in the mixture due to the shale.

These two values added to the 2.15 per cent moisture found in the mixed dust make a total incombustible of $(3.12 + 53.6 + 2.15 =) 58.9$ per cent.

The average of the screen sizes of the roof-shale dust used was as follows:

	Cumulative per cent.
Through 100-mesh.....	100.0
Through 200-mesh (screen A) ^a	99.0
Through 240-mesh.....	96.2

DISCUSSION OF TEST CONDITIONS AND RESULTS.

In test 116 a mixture of 50 per cent coal dust and 50 per cent shale dust, equivalent to 49.8 per cent incombustible matter, was used; the mixture was distributed at the rate of 4 pounds per foot, one-half of it being placed on side shelves and the other half being placed on cross shelves. Ignition was obtained. Pressures exceeding 20 pounds were registered at all stations in the explosion zones.

In test 117 a mixture of 40 per cent coal dust and 60 per cent shale dust was used; this mixture has an incombustible content of 58.2 per cent. The dust was distributed at the rate of 5 pounds per foot from the face of the main entry outby to stations E 950 and A 950. Ignition was obtained, but with lower pressures than were registered in test 116.

In test 146 a similar mixture was distributed with the same amount per foot throughout the same explosion zone, the only difference between the two tests being that in test 146 the walls and roof in the main entry had been cement coated and the floor concreted. No ignition was obtained.

^a In the test at the experimental mine three 200-mesh screens were used, designated A, B, and C, respectively; screen A used in the earlier tests, had holes slightly larger than standard size.

The conclusion based on the comparison of these two tests would be that in test 117 some assistance may have been given to the mixed dust by coal dust from the previous test remaining on the ribs after the cleaning or by particles of rib coal or roof coal taking part in the explosion.

To summarize the results of this series, ignition was obtained in a mixture of Pittsburgh coal dust and roof-shale dust having as great an incombustible content as 58.2 per cent. This result is very nearly the same as the one from tests with limestone dust, in which propagation was obtained through a mixture containing 55.1 per cent incombustible, but not through one containing 64.1 per cent.

SERIES WITH MIXTURES OF PITTSBURGH COAL DUST AND PIT-SHALE DUST.

On account of the complexity introduced in the calculations of the combustible and noncombustible ratios in the mixed dust through the use of shale which contained 9 per cent combustible matter, it was decided to try to obtain a shale practically free from combustible matter. After considerable prospecting such a shale was found 62 feet lower in elevation than the Pittsburgh coal seam. In this a pit was made and subsequently a level drift was opened.

In a series of 13 ignition tests in which pulverized pit-shale dust and pulverized Pittsburgh coal dust were used, seven tests were made with a mixture of 40 per cent coal dust and 60 per cent shale dust; four with a mixture of 30 per cent coal dust and 70 per cent shale dust, and two with a mixture of 25 per cent coal dust and 75 per cent shale dust. Of the seven tests using 40 per cent coal dust and 60 per cent shale dust, two were made with the cannon at the face of the main entry and five with the cannon moved out to the center of the entry at the point E 1247, a point in line with the outby rib of the 1250 cut-through.

The pit shale used in this series analyzed as follows:

Composition of the pit shale.

Loss on ignition (8.90 per cent):	Per cent.
CO ₂	0.82
Organic carbon.....	.39
Organic hydrogen.....	.27
Moisture.....	1.78
Combined water.....	5.64
SiO ₂	50.37
Al ₂ O ₃	22.43
Fe ₂ O ₃	12.01
CaO.....	1.90
MgO.....	2.06
S ₂	.03
SO ₂	.00
K ₂ O+Na ₂ O (by difference).....	2.30

The possible importance of another factor in the standardization of ignition tests was considered and tested—namely, the position of the igniting shot. Officials of the English testing station at Eskmeals had asserted that the most effective position for the igniting shot in their steel gallery was at a point 50 feet from the closed end, basing their assertion on the assisting impulse given by the reflected wave. Therefore a number of tests were made to determine if a corresponding position in the mine entry (in these tests the distance was 61 feet from the face) would give a stronger starting impulse.

RESULTS OF TESTS AND DESCRIPTION OF DETAILS.

Table 12 gives the principal data concerning the test conditions. The percentage of combustible in the shale was so small that it was disregarded in calculating the incombustible in the mixture.

TABLE 12.—Results of ignition tests with mixtures of pulverized Pittsburgh coal dust and pulverized pit-shale dust when no firedamp is present and with small percentages in the air.

[Originating cause: Standard blown-out shot from cannon. Zone: Standard test cone from station E 1300 to station E 960, and from station E 1260 to station A 960; total length 700 feet, unless otherwise noted under remarks.]

Test No.	Date.	Location of igniting shot.	Mixed dust.			Instrument records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocities between stations.						Length of flame in mixed dust zone.	Ignition obtained.
			Ratio of coal dust to shale dust in mixture.	Rate of loading.	Total, loading.	Incombustible in shale plus moisture and ash of coal.	Natural gas used.		Station 1150.	Station 960.	Fall at station 1260.	Velocity.	Fall at station 1150.	Velocity.	Fall at station 960.	
			Lbs. per ft.		Pounds.	Per ct.	Per ct.	Lbs. per sq. ft.	Lbs. per sq. ft.		Seconds.	per sec.	Seconds.	per sec.	Seconds.	Feet.
160	1915. Jan. 19	E 1304	40:60	5	3,500	63.8	0.00	1	1	0						No.
176	Feb. 12	E 1247	40:60	5	3,500	63.8	.00	13	14	16			1.544	198	2.325	Yes.
179	Feb. 20	E 1247	40:60	5	2,250	63.3	.00	13	15	16			1.848	550	2.133	(c)
180	Feb. 20	E 1247	40:60	(c)	(c)	63.3	.00	1	1	0						75 } (b).
181A	Feb. 24	E 1247	40:60	5	3,500	62.9	.00	1	1	0						75 } No.
181B	Feb. 24	E 1247	40:60	(c)	(c)	62.9	.00	1	1	0						25 } No.
181	Jan. 21	E 1304	40:60	5	3,500	66.2	3.44	44					3.448			100 } No.
177	Feb. 17	E 1247	30:70	5	3,500	72.7	.00	65			0.498	390	.761	1,053	.856	100 } Yes.
223	May 20	E 1304	30:70	5	3,500	72.4	1.08	1	1	0						80 } No.
											2.078					60 } No.

223	May 20	E 1304	30 : 70	5	3,500	72.4	2.11	Entry..... (Air course.)	10 17	14 14	1.330	196	2.046 2.200	 1,613	 2,263	412 1,148	2,632 2,349	(*) (*)	Yes. Yes.
178	Feb. 17	E 1304	30 : 70	(*)	(*)	72.7	2.30	Entry..... (Air course.)	23 18	33 23	.710	109	1.631 1.614	634	1.789	972 1,574	1.892 1.741	(*) (*)	Yes. Yes.
224	May 22	E 1304	25 : 75	5	3,500	77.2	1.92	Entry..... (Air course.)	1 1	0 0	.....	.....	.....	.....	.....	.....	.....	25 25	No. No.
225	May 22	E 1304	25 : 75	5	3,500	77.2	2.74	Entry..... (Air course.)	1 1	0 0	.....	.....	.....	.....	.....	.....	.....	100 100	No. No.

* Flame extended through zones.

† No dust was used from stations E 1250 to E 1300 in this test. Barricade at E 1260.

‡ Residue of test 179 plus 150 pounds of fresh dust from stations E 1250 to E 1300 and 200 pounds from stations E 1250 to E 1090.

§ Residue of test 181A plus 200 pounds fresh dust from stations E 1300 to E 1160.

|| Residue of test 177 plus 200 pounds of fresh dust from stations E 1300 to E 1090.

In test 160 the igniting shot was fired from the face of the main entry, and no ignition was obtained through the mixture of 40 per cent coal dust and 60 per cent shale dust. In test 175 a mixture of the same percentages was used, but the cannon was at the point E 1247; in this test an ignition was obtained. Pressures of 14 and 16 pounds were registered at the end of the explosion zone in the entry and air course, respectively. Tests 180, 181A, and 181B were made under conditions similar to those of test 175, but no ignition was obtained.

Ignition of certain dust mixtures which previously had not been ignited, when the cannon was at E 1300, was obtained in only two tests, once in the series with pure Lykens coal and once in the series with Pittsburgh coal (in test 175), but in three other tests with similar arrangements and the same proportions of Pittsburgh coal dust and shale dust as used in test 175 no ignition was obtained.

Test 179 was made with the cannon at the point E 1247, and a barricade was built across the entry at the point E 1260. The reason that at Eskmeal the most effective position for the cannon proved to be 50 feet from the closed end of the gallery is probably that the reflection of the shock wave and air currents from the face assists in stirring up the dust. It was thought, therefore, that placing the barricade across the entry at E 1260 would prevent such reflection from the face of the entry and that comparison of the results of this test with those of test 175 might indicate whether the above theory was correct. Although no ignition was obtained with the barricade at E 1260, neither was it obtained in the three succeeding tests without the barricade; therefore it was concluded that under the conditions in the experimental mine, the effect produced by having the igniting shot near the face of an entry practically did not differ from that produced by having it 61 feet outby. The position at the face was retained because it permitted having a 50-foot ignition zone common to both the entry and the air course and simplified the handling of the instrument records.

IGNITION TESTS WITH METHANE IN AIR.

Test 161 was on a mixture of 40 per cent coal dust and 60 per cent shale dust with the igniting shot at the face of the entry and with 3.44 per cent natural gas in the air current. The explosion was of unusual violence, pressures of 44 and 65 pounds being registered at stations E 1150 and A 1150, respectively.

Test 177 was made with a mixture of 30 per cent coal dust and 70 per cent shale dust, distributed through the usual explosion zone, and with the igniting shot at E 1247. No ignition was obtained. In the following test, No. 178, when the cannon was moved back to the face of the entry and 2.3 per cent of gas was turned into

the air current, an explosion was obtained. Pressures of 23 and 18 pounds were registered at stations E 1150 and A 1150, and of 33 and 23 pounds at stations E 950 and A 950, respectively.

In test 222 the dust mixture was 30 parts coal to 70 parts shale, as in test 177, but the percentage of gas was reduced to 1.08. No ignition occurred. In test 223 the same dust mixture, with 2.11 per cent gas present, was tried. Ignition was obtained, pressures of 10 and 17 pounds being registered at stations E 1150 and A 1150 and 14 pounds at both station E 950 and station A 950. In test 224 the coal content of the mixture was reduced to 25 per cent and a gas content of 2 per cent was attempted, the actual content being 1.92 per cent by analysis. No ignition resulted. The same mixture was again used in test 225, but with 2.74 per cent gas present. No ignition was obtained.

SUMMARY OF DATA OBTAINED AND CONCLUSIONS.

The results of the ignition series with pulverized Pittsburgh coal dust and pit-shale dust may be summarized as follows: Ignition could not be obtained in a mixture containing 62.9 to 63.8 per cent incombustible, except in one test when the cannon was 61 feet outby the face of the entry. Ignition through a mixture containing 72.4 to 72.7 per cent incombustible matter could not be obtained with 1.08 per cent gas in the air current, but was obtained when 2.11 per cent gas was present. Ignition through a mixture containing 77.2 per cent incombustible could not be obtained even with 2.74 per cent gas present.

RÉSUMÉ OF THE RESULTS OF THE THREE SERIES.

The following table summarizes the data on the results of the three series ignition tests with Pittsburgh pulverized dust:

Summary of conditions, and results obtained, in ignition tests of mixtures of pulverized Pittsburgh coal and various incombustible dusts.

Ignition or no ignition.	Gas used.	Limestone-coal mixture.		Roof shale-coal mixture.		Pit shale-coal mixture.	
		Lime-stone in mix-ture.	Incom-busti-ble con-tent.	Shale in mix-ture.	Incom-busti-ble con-tent.	Shale in mix-ture.	Incom-busti-ble con-tent
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Ignition obtained.....	0	50	55.1	60	54.2	60	63.8
Ignition not obtained.....	0	60	64.1	60	58.9	60	62.9-63.8
Ignition obtained.....	3.44					60	63.8
Ignition not obtained.....	0					70	72.4
Do.....	1.08					70	72.4
Ignition obtained.....	2.11					70	72.4
Ignition not obtained.....	1.91					75	77.2
Do.....	2.75					75	77.2

^a In one out of six tests, cannon at E 1247.

^b Freshly cemented test zone.

The results of the different tests seem consistent, on the basis of comparison of percentages of incombustible matter, except for the ignition of the pit shale-coal dust mixture having 63.8 per cent incombustible. In this test, however, the cannon was not in the usual position, and no ignition was obtained in three other tests made under the same conditions. On the basis of mixture percentages, the results are equally consistent. The only variant, the same as above (test 175), was one ignition, which compares with five nonignitions of that mixture (40 coal dust, 60 pit shale). From this series of tests it would seem that the combustible matter in the roof shale (9 per cent) does not enter into the combustion reactions in an explosion and that the three kinds of inert dust tried differ but little in their effects.

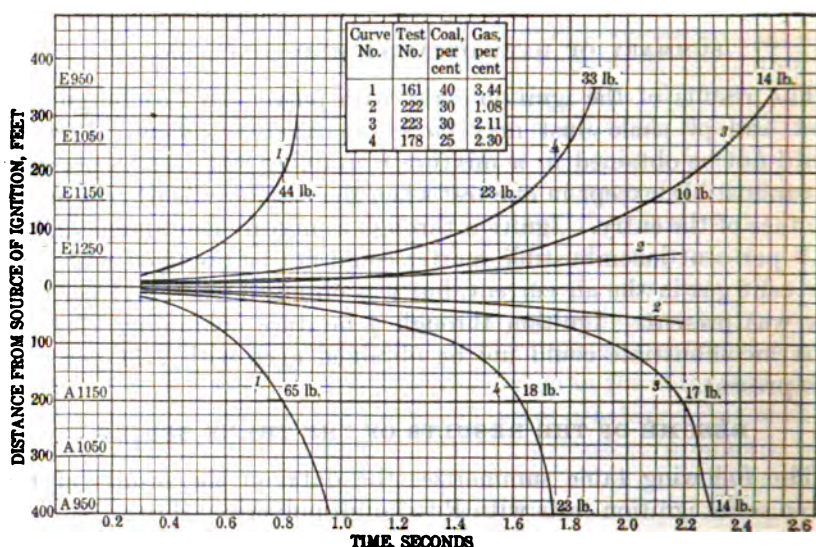


FIGURE 24.—Flame velocity curves for ignition tests on pulverized Pittsburgh coal and pulverized shale. Italic figure near curve denotes number of curve, roman figure denotes pressure in pounds per square inch at that point.

CURVES OF FLAME VELOCITIES IN TESTS WHERE FIRE DAMP WAS USED.

The curves in figure 24 show graphically the relative velocities of flame in some of the tests of this series. In test 161 (curve 1) a mixture containing 40 per cent coal dust and 60 per cent shale dust, with 3.44 per cent of gas in the air current, produced high velocities, the rate in the last 200 feet reaching 6,660 feet per second. Maximum pressures of 44 pounds and 65 pounds were registered at stations E 1150 and A 1150, respectively. Pressures of 12 and 20 pounds, registered at the time the tin-foil record was obtained, indicate more or less

accurately the pressure accompanying the advancing explosion wave at these points. The higher pressures registered at these points later was due in part to pressures from retonation waves traveling toward the face of the entry. The manometers of the B, C, D type which were used in stations outby E 950 and A 1150 failed to record the peaks of pressure in this very fast violent explosion.

In test 222 (curve 2), a 30 per cent coal-70 per cent shale dust mixture, with 1.08 per cent of gas present, gave slow velocities through the short distance the flame traveled before dying out.

Test 223 (curve 3), with the same dust mixture, with 2.11 per cent gas present, showed the slowest velocities recorded in any of the tests where ignition was obtained.

Test 178 (curve 4), with the same dust mixture, but with 2.30 per cent gas present, showed the effect of the increased gas percentages, the velocities, and pressures developed being higher than in test 223.

PROPAGATION TESTS WITH 100-FOOT IGNITION ZONES OF PURE COAL DUST.

SERIES WITH MIXTURES OF PITTSBURGH COAL DUST AND ROOF-SHALE DUST.

DESCRIPTION OF TESTS AND RESULTS.

Five propagation tests were made with ignition zones of 100 feet of pure Pittsburgh coal dust in which the mixtures tested were composed of pulverized Pittsburgh coal dust and pulverized roof-shale dust. The data for these tests are given in Table 13.

The flame from the explosion of a 100-foot coal-dust zone, as determined in test 82, is 250 feet in length, or extends 150 feet into the dustless zone beyond the end of the coal-dust zone. In the tests of this series (Nos. 56, 59, 60, 77, and 78) no dust was placed in the 1,250 cut-through or in the air course.

The dust was distributed on side shelves only, there being no cross shelves at the time these tests were made. In the first three tests the combustible content in the shale dust was about 10 per cent; in the last two tests it was nearly 7 per cent. In four of these tests a mixture of 50 per cent coal dust and 50 per cent shale dust was used, and in three of the four tests propagation was obtained to the end of the zone. In test 60 propagation was not obtained.

158 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

TABLE 13.—*Results of propagation tests, with 100-foot coal-dust ignition zone, of mixtures of pulverized Pittsburgh coal dust and pulverized roof-shale dust.*

[Originating cause: Standard blown-out shot from cannon at station E 1300.]

Test No.	Date.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Maximum pressures.			
			Zone, length, and rate of loading.	Total amount of dust.	Calculated content of incombustible.	Station E 1150.	Station E 950.	Station E 750.	Station E 550.
56	1913. Dec. 4	50:50	Stations E 1200 to E 700, 500 feet at 2 pounds per foot.	Pounds 1,000	Per ct. 51.8	Lbs. per sq. ft. 5	Lbs. per sq. ft. 5	Lbs. per sq. ft. 13	Lbs. per sq. ft. 6
59	Dec. 10	50:50	Stations E 1200 to E 700, 500 feet at 2 pounds per foot.	1,000	50.6	-----	0	0	0
60	Dec. 18	50:50	Stations E 1200 to E 700, 500 feet at 2 pounds per foot.	1,000	50.8	3	0	0	0
77	1914. Jan. 28	50:50	Stations E 1200 to E 500, 700 feet at 4 pounds per foot.	2,800	49.4	5	-----	7	6
78	Jan. 29	40:60	Stations E 1200 to E 300, 900 feet at 5 pounds per foot.	4,500	57.8	-----	0	0	0

Test No.	Time of tin-foil rupture at stations and flame velocity between stations.							Length of flame in mixed-dust zone.	Propagation obtained.
	Foil at station E 1150.	Velocity.	Foil at station E 950.	Velocity.	Foil at station E 750.	Velocity.	Foil at station E 550.		
56	Seconds. 1.359	Ft. per sec. 511	Seconds. 1.750	Ft. per sec. 606	Seconds. 2.080	Ft. per sec. 156	Seconds. 3.366	Ft. (a)	Yes.
59	1.036	49	5.102	-----	-----	-----	-----	(a)	Yes.
60	1.300	-----	-----	-----	-----	-----	-----	275	No.
77	0.928	406	1.421	548	1.786	1,123	1.958	(a)	Yes.
78	1.012	128	2.577	67	5.558	-----	-----	450	No.

* Flame extended through zone.

In test 78 a mixture of 40 per cent coal dust and 60 per cent shale dust, equivalent to 57.8 per cent incombustible material, was distributed along a zone 900 feet in length. Propagation to the end of the zone was not obtained. A study of the flame-indicator records shows that the explosion gradually lost speed from the time it left the 100-foot zone of pure coal dust until it died away at station E 750.

CONCLUSIONS FROM TESTS.

Propagation of an explosion started in an ignition zone of 100 feet of Pittsburgh coal dust can be obtained through a mixture of Pittsburgh dust and roof shale having 51.8 per cent incombustible, but not through one having 57.8 per cent incombustible. The propagation limit as determined by this arrangement of zones gives a mixture

of about the same incombustible content as that given by the later ignition tests in which both entries were loaded, the dust being placed on cross shelves. It is very probable that a higher propagation limit would have been obtained if the arrangement of dust distribution that was developed later had been in use at the time these tests were made; also had there been coal dust loading in the cut-through, the pressure at the initiation would have been sustained and given a stronger impetus.

SERIES WITH MIXTURES OF PITTSBURGH COAL DUST AND LIMESTONE DUST.

CHARACTER AND RESULTS.

The arrangement of zones and the method of dust distribution used in this series, consisting of three tests, was similar to those of the preceding series except that limestone dust was used instead of roof-shale dust.

The essential data on these tests are presented in Table 14.

TABLE 14.—*Data on propagation tests, with 100-foot coal-dust ignition zones, of mixtures of pulverized Pittsburgh coal dust and limestone dust.*

[Originating cause: Standard blown-out shot from cannon at station E 1300; mixed dust zone, stations E 1200 to E 700; length, 500 feet.]

Test No.	Date.	Mixed dust.				Maximum pressures.		
		Ratio of coal dust to limestone dust in mixture.	Rate of loading.	Total amount of dust used.	Incombustible in limestone plus moisture and ash of coal.	Station E 1150.	Station E 950.	Station E 750.
72	1914. Jan. 15	50 : 50	<i>Lbs. per ft.</i> 4	<i>Pounds.</i> 2,000	<i>Per ct.</i> 55.7	<i>Lbs. per sq. in.</i>	0	0
73	Jan. 18	60 : 40	3½	1,665	45.5	.....	0	0
74	Jan. 21	60 : 40	3½	1,665	45.6	.....	0	0

Test No.	Time of tin-foil rupture at stations and flame velocities between stations.									Length of flame in mixed dust zone.	Propagation obtained.
	Foil at station E 1150.	Ve-locity.	Foil at station E 1060.	Ve-locity.	Foil at station E 950.	Ve-locity.	Foil at station E 860.	Ve-locity.	Foil at station E 750.		
72	<i>Sec-onds.</i> 1.194	<i>Ft. per second.</i>	<i>Sec-onds.</i>	<i>Ft. per second.</i>	<i>Sec-onds.</i>	<i>Ft. per second.</i>	<i>Sec-onds.</i>	<i>Ft. per second.</i>	<i>Sec-onds.</i>	<i>Feet.</i> 225	No.
73	1.135	190	1.638	133	2.391	134	3.125	293	3.468	(*)	Yes.
74	1.157	253	1.552	243	1.962	113	2.846	1,515	2.912	(*)	Yes.

* Flame extended through zone.

DISCUSSION OF THE RESULTS.

In test 72 a mixture of 50 per cent coal dust and 50 per cent limestone dust was used, but propagation was not obtained. Duplicate tests (Nos. 73 and 74) were made with a mixture of 60 per cent coal dust and 40 per cent limestone dust; this mixture contained about 45 per cent incombustible matter. The flame passed through the zone, but the pressures developed were so light as to give practically no record on the manometers. Comparison of these tests with the ignition tests of limestone-dust mixtures previously described (p. 144) shows that the ignition limit with side shelves and double-entry loading is practically the same as the propagation limit with side shelves and single-entry loading. However, when an ignition test was made with the mixed dust loaded on cross shelves ignition was obtained through a 50 per cent coal-dust and 50 per cent limestone-dust mixture having an incombustible content of 56.1 per cent. Hence if propagation tests had been made using a coal-dust ignition zone 100 feet in length and placing the mixed dust on cross shelves propagation would have been obtained through the mixture containing 50 per cent each of coal dust and limestone dust.

PROPAGATION TESTS WITH 300-FOOT IGNITION ZONES OF PURE COAL DUST.**SERIES ON MIXTURES OF PITTSBURGH COAL DUST WITH ROOF-SHALE DUST AND WITH LIMESTONE DUST.**

Five tests were made to determine how much the propagation limit of Pittsburgh coal dust would be raised by using a stronger means of ignition. Pure pulverized Pittsburgh coal dust was distributed on side shelves along a 300-foot ignition zone extending from the face of the main entry to the point E 1000, additional dust being placed in the 1250 cut-through. The explosions were started by firing a blown-out shot from a cannon at the face of the entry.

In test 92 a mixture of 40 per cent pulverized Pittsburgh coal dust and 60 per cent pulverized roof-shale dust was distributed from E 1000 to E 200 at the rate of 5 pounds per foot. A large part of the coal dust used in the ignition zone was very fine dust, taken from the cyclone collector in the grinding house, 95 per cent passing through 240-mesh. As a result the pressure at station E 950 (58 pounds) was considerably greater than any pressure previously obtained at this point from a 300-foot coal-dust zone. At station E 750 the pressure was 49 pounds, and at stations E 550 and E 350 the pressure was about the same, propagation being obtained through the mixed-dust zone. The results of the test therefore indicate that this mixture, which is equivalent to 57.9 per cent incombustible matter, will propagate an explosion.

In test 95 a mixture of 30 per cent pulverized Pittsburgh coal dust and 70 per cent pulverized roof-shale dust and containing 68.3 per cent incombustible matter was used. Propagation was obtained throughout the zone. The pressure at station E 950 was 31 pounds, dropped to 22 pounds at station E 750, and then increased to 28 pounds at station E 550 and to 41 pounds at station E 350. The fact that the pressure increased from station E 750 to station E 350 indicates that this mixture is explosive.

A mixture containing 20 per cent pulverized Pittsburgh coal dust and 80 per cent pulverized roof-shale dust, equivalent to about 75 per cent incombustible matter, was distributed from E 1000 to E 200 in test 93, and from E 1000 to E 300 in test 94. The length of flame in both tests was the same, the last guncotton tuft burned being at station E 325, 675 feet beyond the end of the pure coal-dust zone. In both tests the pressures decreased as the explosion advanced through the mixed-dust zone, indicating that the mixed dust had a quenching effect upon the explosion.

In test 102 a mixture composed of 25 per cent pulverized Pittsburgh coal dust and 75 per cent limestone dust and containing about 78.5 per cent incombustible matter was used. The last guncotton burned in this test was at station E 500, 500 feet beyond the end of the pure coal-dust zone, so that this mixture quenched the explosion more rapidly than the one having 20 per cent coal-dust and 80 per cent shale-dust mixture. The pressure at station E 950, however, was only 7 pounds, which is less than had been obtained in any of the preceding tests; that is, the starting impulse from the pure coal-dust ignition zone was less for some unexplained reason. The essential data on these tests are presented in Table 15. The results of these tests with strong ignition loading (coal dust being loaded along a 300-foot entry zone and in the cut-through) indicate that the propagation limit is naturally higher than the limit obtained when a 100-foot ignition zone was used. It should be noted that cross shelving was not used in either series, this method not having been developed at that time.

TABLE 15.—Data for propagation tests, with 300-foot coal-dust ignition zones, of mixtures of pulverized Pittsburgh coal dust and pulverized roof-shale dust and with limestone dust.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Ignition zone: Pulverized Pittsburgh coal dust stations E 1300 to E 1000 and the 1250 cut-through.]

Test No.	Date.	Mixed dust.				Maximum pressure.			
		Kind of dust. ^a	Calculated incombustible.	Zone, length and rate of loading.	Total amount of dust.	Station E 950.	Station E 750.	Station E 550.	Station E 350.
92	1914. Feb. 25	40 coal, 60 shale..	Per ct. 57.9	E 1000 to E 300, 800 feet at $\frac{1}{6}$ pounds per foot.	Pounds 4,000	Lbs. per sq. in. 58	Lbs. per sq. in. 49	Lbs. per sq. in. 50	Lbs. per sq. in. 43
95	Mar. 10	30 coal, 70 shale..	68.3	E 1000 to E 200, 800 feet at $\frac{1}{6}$ pounds per foot.	4,000	31	22	23	41
93	Mar. 4	20 coal, 80 shale..	75.5	E 1000 to E 200, 800 feet at $\frac{1}{6}$ pounds per foot.	4,000	58	11	5	.....
94	Mar. 6	20 coal, 80 shale..	75.0	E 1000 to E 300, 700 feet at $\frac{1}{6}$ pounds per foot.	3,500	27	14	10	2
102	Mar. 31	25 coal, 75 lime- stone.	75.5	E 1000 to E 300, 800 feet at $\frac{1}{6}$ pounds per foot.	4,000	7	5	2	5

Test No.	Time of tin-foil rupture at stations and flame velocity between stations.									Length of flame in mixed dust zone.	Propagation obtained.
	Foil at station E 1150.	Velocity.	Foil at station E 950.	Velocity.	Foil at station E 750.	Velocity.	Foil at station E 550.	Velocity.	Foil at station E 350.		
92	Sec- onds. 0.728	Feet per second. 3,226	Sec- onds. 0.790	Feet per second. 3,333	Sec- onds. 0.850	Feet per second. 2,127	Sec- onds. 0.944	Feet per second. 2,063	Sec- onds. 1.041	Feet. (b)	Yes.
95	.752	1,098	.934	3,080	1.000	1,307	1.153	2,020	1.252	(b)	Yes.
93	.827	631	1.144	.....	.....	252	.....	.....	3.529	675	No.
94	.795	746	1.063	1,786	1.175	1,266	1.333	330	1.923	675	No.
102	.871	419	1.348	201	2.342	.....	.....	.....	.....	500	No.

^a Number indicates percentage.^b Flame extended through zones.

PROPAGATION TESTS WITH 50-FOOT IGNITION ZONES AND LOADING IN AIR COURSE.

As a result of the various trials—up to April, 1914—of different arrangements to obtain consistent and comparable results and at the same time to obtain simultaneous duplicate tests, it was decided to try using both entries in each test, with a common starting origin. It was also decided that a 50-foot ignition zone of pure pulverized Pittsburgh dust, always loaded in exactly the same way, would give sufficient impulse—equivalent to a body of fire damp—for propagation testing of various coal dusts and mixtures.

Therefore, following test 104, a large number of tests were made with mixtures of Pittsburgh coal dust and incombustible dust, either roof shale or pit shale, in order to determine the least percentage of shale dust that would prevent propagation of an explosion, and incidentally to make efficiency tests on the rock-dust barriers. These tests are tabulated in two sets, those in which the incombustible material was roof-shale dust and those in which the incombustible material was pit-shale dust.

SERIES ON MIXTURES OF PITTSBURGH COAL DUST AND ROOF-SHALE DUST.

DESCRIPTION AND RESULTS.

Thirteen tests were made with mixtures of pulverized Pittsburgh coal dust and pulverized roof-shale dust to determine the lowest percentage of shale dust that would prevent propagation through the mixture of an explosion started in a 50-foot ignition zone of pure coal dust. Data on these tests are presented in Table 16 herewith. Tests with numbers below 140 were made in the mine before the explosion zone had been concreted, whereas tests with later numbers than 140 were made in the concreted zone. The igniting shot was fired from the cannon at the face of the main entry in all tests except Nos. 139, 111, and 111B, in which it was fired from the face of the stub off the 1250 cut-through. In all tests both entries were loaded with the mixture being tested; also, after test 115 the important change of loading part of the dust on cross-shelves was employed, giving more sensitive propagation conditions and more consistent results.

TABLE 16.—Data for propagation tests, with 50-foot coal-dust ignition zones and double-entry loading, of mixtures of pulverized Pittsburgh coal dust and pulverized roof-shale dust.

[Originating cause: Standard blown-out shot from cannon. Ignition zone loaded with pulverized Pittsburgh coal dust.]

IGNITING SHOT AT STATION E 1300; IGNITION ZONE, FROM STATIONS E 1300 TO E 1230.

Test No.	Date.	Ratio of coal dust to shale in mixture.	Mixed dust.			Instru-ment records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Propa-gation ob-tained.
			Calcu-lated incombustible.	Zone and length.	Rate of load-ing.	Powd-ers.	Sta-tion 1150.	Sta-tion 950.	Foil at station 1250.	Ve-locity.	Foil at station 1150.	Ve-locity.	Foil at station 1050.	Ve-locity.	Foil at station 950.	
104	1914. Apr. 16	60:40..	Per c. 42.2	E 1250 to E 950, 300 E 1250 to A 950, 350 Total..... 650	3½	2, 163	8	9								Yes.
							12									
107	Apr. 23	50:50..	49.4	E 1250 to E 950, 300 E 1250 to A 950, 350 Total..... 650	4	2, 600	6	7	0.631	286	1.054	313	1.100	475	1.475 1.560	Yes.
							9				0.977			200		
108	Apr. 27	40:60..	60.2	E 1250 to E 900, 450 E 1250 to A 950, 350 Total..... 800	5	4, 000	2	0			1.601	63	2.208			Yes. ^b
							1	0			1.495	67	2.965		250 (c)	
147	Dec. 2	40:60..	58.8	E 1250 to E 950, 300 E 1250 to A 950, 350 Total..... 650	5	3, 250	3	2	.550	57	2.294	292	2.676	695	2.922 2.983	Yes. ^d
							4				1.965	191	2.458	244		
149	Dec. 8	35:65..	62.3	E 1250 to E 950, 300 E 1250 to A 950, 350 Total..... 650		3, 250	4	3	.609	285	1.094	161	1.854	323	1.953 1.981	Yes. ^d
							6				1.419	358	1.904	429		
110	May 2	30:70..	68.2	E 1250 to E 900, 450 E 1250 to A 950, 350 Total..... 800	10	8, 000	1	1			1.693	173	2.240	115	2.110 2.110	Yes. ^b
											1.964				425 (c)	

112	May 7	30-70..	67.7	E 1250 to F 950. 300 E 1250 to A 950. 350 Total..... 1,150	10	11, 800	{Entry..... {Air course.....	1 2	2	.672	34	3, 436 1, 534	 320	1, 547	433 326	4, 098 2, 136	575 (e)	} Yes. ^d
150	Dec. 11	30-70..	67.2	E 1250 to F 950. 300 E 1250 to A 950. 350 Total..... 650	5	3, 250	{Entry..... {Air course.....	 6	4 3	.695	82	1, 902 2, 141	251 621	2, 301 2, 302	181 402	2, 854 2, 531	(e)	} Yes. ^d
155	Dec. 31	25-75..	70.3	E 1250 to F 950. 300 E 1250 to A 950. 350 Total..... 650	5	3, 250	{Entry..... {Air course.....	2 1	1 1	.735	17	6, 517 .....	.....	.....	.....	.....	200 225	} No. ^d
156	1915. Jan. 5	25-75..	66.8	E 1250 to F 950. 300 E 1250 to A 950. 350 Total..... 650	5	3, 250	{Entry..... {Air course.....	2	 1	.642 .....	..... .....	..... 2, 616	71 75	2, 440 2, 953	23 59	7, 832 5, 075	(e)	} Yes. ^d

IGNITING SHOT IN STUB ENTRY OFF 1250 CUT THROUGH; IGNITION ZONE IN STUB ENTRY AND 1250 CUT THROUGH.

139	1914. July 15	50-50..	.....	E 1250 to F 950. 300 A 1250 to A 975. 375 Total..... 675	4	2, 700	{Entry..... {Air course.....	21	25 16	0.820	1, 938	0.874 .784	1, 034 496	0.938 .956	840 258	1, 087 1, 374	(e)	} Yes. ^d
111	May 5	40-50..	58.3	E 1250 to F 950. 450 A 1250 to A 950. 300 Total..... 750	5	3, 750	{Entry..... {Air course.....	0 0	0 0	{c} {c}	{c} {c}	{c} {c}	{c} {c}	{c} {c}	.....	.....	0 95	} No.
111B	...do...	40-50..	58.3	E 1250 to F 950. 450 A 1250 to A 950. 300 Total..... 750	5	3, 750	{Entry..... {Air course.....	2 2	2 2	..... .....	..... .....	..... .....	..... .....	2, 758 1, 740	676	2, 904	(e)	} Yes.

* Flame extended through zones.

† Flame extended through zone in one entry.

* No records.

* Leading on cross shelves.

DISCUSSION OF TESTS AND RESULTS.

Propagation was obtained in test 104 with a mixture containing 60 per cent coal dust and 40 per cent shale dust. Propagation was obtained in test 107, with a 50 per cent coal-dust and 50 per cent shale-dust mixture containing 49.4 per cent incombustible matter. In test 139 the mixture tested was the same as in test 107, but the igniting shot was fired from the offset from the 1250 cut-through, pure Pittsburgh coal dust being distributed in the offset and the cut-through and mixed dust in the parallel entries. In this test some of the dust was loaded on cross shelves, in addition to the usual distribution on side shelves. The flame reached station E 950 in 1.09 seconds, and pressures of 25 and 16 pounds were recorded at stations E 950 and A 950, respectively.

In tests 108, 111, 111B, and 147 mixtures of 40 per cent coal dust and 60 per cent shale dust (incombustible content of mixture, 58.3 to 60.2 per cent) were tested. In tests 108 and 147 the cannon was at the face of the entry, whereas in tests 111 and 111B it was placed in the stub entry off the 1250 cut-through. In test 108 complete propagation was not obtained, probably on account of the damp condition of the entry. In test 111 propagation was not obtained, possibly through poor distribution of the coal dust in the ignition zone stub entry and 1250 cut-through. In test 111B, with the same mixed dust as in test 111, but with fresh coal dust in the ignition zone, a weak explosion was obtained. In test 147 complete propagation was obtained; the velocities on the main entry were very similar to those of test 111B, and the pressure at station E 950 (7 pounds per square inch) was somewhat greater. The explosion zone had been concrete lined prior to the time of test 140.

In test 149, with a mixture containing 35 per cent coal dust and 65 per cent roof-shale dust and having 62.3 per cent incombustible matter, complete propagation was obtained. The time of the tin-foil rupture at station E 950 was 1.96 seconds, as compared with 2.82 seconds in test 147, in which a mixture of 40 per cent coal dust and 60 per cent shale dust was used. The reason for the faster explosion being obtained with the higher shale percentage is not known.

In tests 110, 112, and 150 a mixture containing 30 per cent coal dust and 70 per cent roof-shale dust and having about 67½ per cent incombustible matter was used. In test 110 the main-entry zone was 450 feet in length. The dust both in this zone and in the air course was distributed at the rate of 10 pounds of mixed dust per foot, some of the dust being placed upon the floor. Complete propagation was obtained in the air course, but not in the entry. In test 112 the entry zone was extended to station E 450, or a total length of 800 feet outby the ignition zone. The distribution in both this

zone and in the air course was at the rate of 10 pounds of mixed dust per foot, about one-half to two-thirds of the dust being placed upon the floor. The floor was very damp and the mixed dust placed on it immediately became wet; therefore this dust probably had no effect on the explosion. The flame extended only to the point E 675 in the main entry, so the propagation was not complete. In test 150 the zones extended only to stations E 950 and A 950, and the dust was distributed at the rate of 5 pounds per foot on cross shelves, side shelves, and the concrete floor. Propagation was obtained throughout the zone. However, the velocities in the last 100 feet were less than those in the inby 100 feet; hence it is uncertain whether complete propagation would have been obtained through a zone of greater length.

Tests 155 and 156 were made with mixtures of 25 per cent coal dust and 75 per cent shale, the incombustible content being 70.3 and 69.8 per cent, respectively. In the former, propagation was not obtained; in the latter, a weak explosion resulted. The velocities between stations 1050 and 950 on the entry and air course were 23 and 89 feet per second, respectively. The explosion would undoubtedly have died away had the zone been longer.

The curves in figure 25 show how the velocity of the flame, as indicated by rupture of tin-foil circuit breakers, slows up as the percentage of ash increases. Figure 26 shows the flame velocity for the tests in which the cannon was placed in the offset from the 1250 cut-through.

SUMMARY.

It was possible to obtain propagation through a zone of mixed dust composed of 75 per cent roof-shale dust and 25 per cent pulverized coal dust.

SERIES WITH PITTSBURGH COAL DUST AND PIT-SHALE DUST.

Twenty-six tests were made with mixtures of Pittsburgh coal dust and pit-shale dust; the results of these are presented in Table 17. Tests with numbers ranging from 142 to 200 were made in the earlier part of the testing period for determining the propagation limits, for trying out barriers, and for comparison with tests in which roof-shale dust was used. With one exception (test 145), the igniting shot was fired from a cannon placed at the face of the main entry. In test 145 the cannon was placed in the stub entry off the 1250 cut-through. The distribution in these tests was usually at the rate of 2 pounds of coal dust per foot, except that in tests where the total quantity of mixed dust would have exceeded 5 pounds per foot the amount of

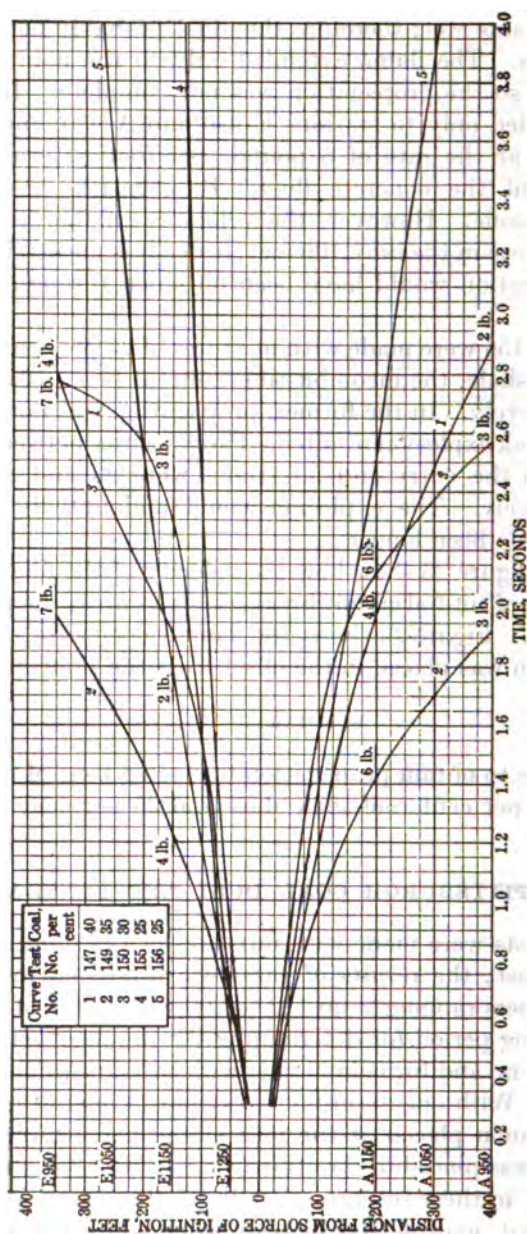


FIGURE 25.—Flame velocity curves for propagation tests with mixtures of pulverized Pittsburgh coal dust and pulverized roof shale; 50-foot ignition zone, cannon at station E 1300. Italic figures near curve denote number of curve; roman figures denote pressure developed at that point. 0, represents origin at cannon; figures and curves above zero line are for entry results and below that line for air-course results.

coal dust was reduced so that the total of mixed dust would not exceed 5 pounds per foot.

At a later period a large number of tests were made to determine the influence of the size and quantity of dust present on the propagation of an explosion. While these experiments were in progress further

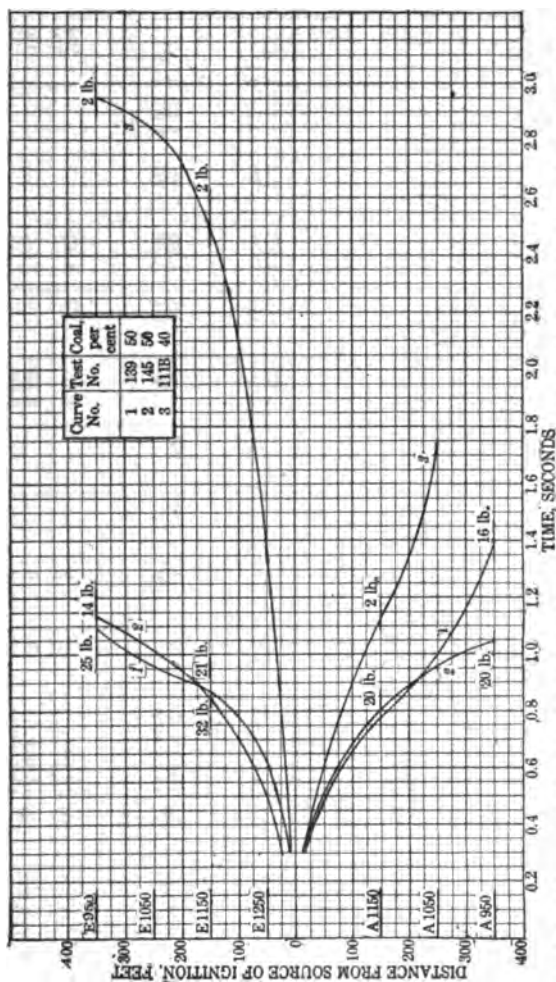


FIGURE 26.—Flame-velocity curves for propagation tests of mixtures of pulverized Pittsburgh coal dust and pulverized roof shale and pulverized pit shale. Ignition in stub entry of 1280 cut-through. Italic figures denote number of curve; roman figures denote pressure developed, in pounds per square inch at that point. 0, represents origin at cannon; figures and curves above zero line are for entry results and below that line for air-course results.

propagation tests were made with the mixtures of pulverized coal and shale dusts. As the results of these later tests showed slight modifications in the propagation limits, they are included in this series. In addition two other tests (Nos. 323 and 324) were made to get more exact information on the propagation limits when gas was present in the air current.

TABLE 17.—Data for propagation tests, with 50-foot ignition zones, of mixtures of pulverized Pittsburgh coal dust and pulverized pit-shale dust.
[Originating cause—Standard blown-out shot from cannon at station E 1300. Ignition zones E 1300 to E 1250, pulverized Pittsburgh coal dust. Mixed-dust zone—E 1250 to E 950, 300 feet; and E 1250 to A 950, 350 feet; total length, 650 feet.]

Test No.	Date.	Mixed dust.				Natural gas used.		Records obtained in entry or in air course.		Maximum pressure registered.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
		Ratio of coal dust to pit-shale dust in mixture.	Calculated content of combustible.	Rate of loading.	Total loading.	Per cent.	Per d.	Entry.....	Per d.	Lbs. per sq. ft.	Lbs. per sq. ft.	Fall at station 1250.	Velocity.	Fall at station 1150.	Velocity.	Fall at station 1050.	Velocity.	Fall at station 950.	
		(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	Secs.	Ft. per sec.	Secs.	Ft. per sec.	Secs.	Ft. per sec.	Secs.	
191	1915. Mar. 19							Entry.....	0.00	1	1	0.272							Test made to determine length of flame from standard ignition zone.
198	Apr. 8	(a)	(a)	(a)	(a)	(a)	.00	Entry.....	.00	1	1	.411							Do.
376	1917. Jan. 26	(a)	(a)	(a)	(a)	(a)	.00	Entry.....	.00	1	1	.291							Do.
143	1914. Oct. 30	50:50	56.5	4	2,600	.00	.00	Entry.....	.00	4	2		1.479	2.401	66	2.992	232	3.422	Propagation obtained.
								Air course.		5	7				190	3.331	298	3.717	Do.
145	Nov. 9	50:50	56.4	4	2,600	.00	.00	Entry.....	.00	32	14	.463	256	.853	591	1.022	981	1.124	Propagation obtained. This test was the only one of the series in which the cannon was placed in the stub off 1250 cut through the stub and cut through being used as the lighting zone.
								Air course.		20	20			.707	671	.946	917	1.055	Do.
142	Oct. 29	40:60	63.9	5	3,250	.00	.00	Entry.....	.00	1	0			1.577	53	3.475			Propagation not obtained.
								Air course.		1	0								Do.
144	Nov. 4	40:60	64.1	5	3,250	.00	.00	Entry.....	.00	1	0			3.502					Do.
								Air course.		1	0			6.010					Do.
151	Dec. 14	40:60	63.6	5	3,250	.00	.00	Entry.....	.00	2	0	.438	91	1.437	92	2.622	74	3.973	Propagation obtained in entry, but not in air course.
								Air course.		13	19	1.111	129	1.898	310	2.982	502	2.200	Do.
152	Dec. 15	40:60	63.5	5	3,250	.00	.00	Entry.....	.00	13	10			1.635	304	1.846	497	2.047	Propagation obtained.
								Air course.		10	14								Do.

153	Dec. 22	30 : 70	72.8	5	3,250	.00	{Entry..... Air course.	1	1	1	1	1.132	97	2,159	25	6,106	.....	.....	(c) 300	Propagation obtained in entry, but not in air course.
299	1916. Mar. 15	30 : 70	71.8	13	1,083	.00	{Entry..... Air course.	4	4	4	4	.354	213	.823	153	1,475	183	2,020	(b)	Propagation obtained.
305	Mar. 31	30 : 70	71.9	131	8,667	.00	{Entry..... Air course.	2	1	1	1	.493	126	1,267	63	2,866	144	3,560	(b)	Do.
300	Mar. 17	25 : 75	76.4	2	1,300	.00	{Entry..... Air course.	3	3	2	2	.441	171	1,027	79	2,285	121	3,005	225	Propagation obtained in air course, but not in entry.
377	Apr. 3	25 : 75	76.6	2	1,300	.00	{Entry..... Air course.	2	1	1	1	.....	.....	1,022	154	1,670	147	2,350	(b)	Propagation not ob- tained.
264	1915. Dec. 22	25 : 75	76.6	4	2,600	.00	{Entry..... Air course.	2	2	2	2	.680	177	1,186	118	2,083	131	2,796	(b)	Propagation obtained.
154	1914. Dec. 28	25 : 75	77.8	5	3,250	.00	{Entry..... Air course.	2	1	1	1	.....	.....	7,048	.....	.....	.....	100	Propagation not ob- tained.	
157	1915. Jan. 8	25 : 75	77.6	5	3,250	.00	{Entry..... Air course.	1	1	0	1	2,284	22	6,896	.....	.....	.....	125	Do.	
267	1916. Jan. 5	25 : 75	76.8	8	5,200	.00	{Entry..... Air course.	1	1	2	2	.308	56	2,092	49	4,130	.....	175	Do.	
268	Jan. 7	20 : 80	81.4	5	3,250	.00	{Entry..... Air course.	2	1	1	1	.428	128	1,212	150	.....	.....	225	Do.	
199	1915. Apr. 9	(e)	(e)	(e)	(e)	2.68	{Entry..... Air course.	1	1	0	1	.232	.....	.....	.....	.....	.....	180	Test made to obtain length of flame from ignition zone, with about 2 per cent gas present.	
200	Apr. 10	(e)	(e)	(e)	(e)	2.29	{Entry..... Air course.	1	1	0	1	.....	.....	.....	.....	.....	.....	85	Do.	
153	Jan. 12	25 : 75	77.3	5	3,250	.96	{Entry..... Air course.	1	1	0	1	.744	62	2,366	.....	.....	.....	175	Propagation not ob- tained.	
159	Jan. 15	25 : 75	77.3	5	3,250	2.97	{Entry..... Air course.	1	3	2	2	.457	132	1,213	51	3,168	97	4,204	(b)	Propagation obtained in entry, but not in air course.
324	1916. May 13	20 : 80	81.6	5	3,250	1.12	{Entry..... Air course.	2	2	2	2	.449	155	1,086	49	6,640	.....	150	Propagation not ob- tained.	
323	May 11	20 : 80	81.8	5	3,250	1.71	{Entry..... Air course.	3	3	3	3	.424	146	1,111	60	2,776	108	3,699	(b)	Propagation obtained.
182	1915. Feb. 25	20 : 80	81.3	5	3,250	3.02	{Entry..... Air course.	7	15	9	9	.373	179	.633	211	1,407	746	1,531	(b)	Do.
								12								1,166	455	1,386		

* Flame extended through zones.

* Mixed dust not used.

DISCUSSION OF RESULTS.

Tests 191, 198, and 376 were made with a starting zone of 50 feet of pulverized Pittsburgh coal dust with a dustless zone outby. Some time prior to the time these tests were made the main entry and the air course had been concreted from the face out to E 950 and A 950, and it was possible to get a more nearly dustless zone than before this concreting was done. In test 191 the flame, as indicated by burned matches, extended 25 feet beyond the coal-dust zone, and in tests 198 and 376, as indicated by sensitive photographic paper, 35 feet and 50 feet, respectively.

In test 143 a mixture of 50 parts coal dust and 50 parts shale dust and containing 56.5 per cent incombustible matter was distributed at the rate of 4 pounds per foot on cross shelves. Propagation was obtained to the end of the zone. In test 145 the same mixture as that of test 143 was used, but the cannon was placed in the stub entry off the 1250 cut-through, the stub and cut-through being used as an ignition zone and the mixed dust being distributed in the two parallel entries. The resulting explosion was more rapid and developed higher pressures than that of test 143. The reason for this is not apparent.

In tests 142 and 144 a mixture of 40 parts coal dust and 60 parts shale dust was used, the dust being placed on cross shelves only; in both of these tests propagation was incomplete. At the time they were made the concreting had not been completed entirely in the air course, and it was possible that the zones were not as clean and that they were also wetter than they might otherwise have been.

The work of concreting had been completed before tests 151 and 152 were made and it was possible to clean the zones much more completely. With a mixture of the same percentage distributed throughout the zones on cross shelves, side shelves, and floor, thus giving a greater area of distribution, complete propagation was obtained, although test 151 was a very weak explosion. In test 152 much higher pressures were obtained, those in the main entry being 13 and 19 pounds at stations 1150 and 950, respectively, and 10 and 8 pounds at corresponding stations in the air course.

A comparison of times of rupturing tin-foil indicators at corresponding stations of the entry and the air course in tests 143, 144, 151, and 152 is of interest. The flame reached station A 1150, in the first three tests, much later than station E 1150, and in test 143 the time was nearly twice as long; the velocity of flame between the 1150 and 1050 stations in the air course, as indicated by the rupture of the foils, was nearly three times the corresponding velocity in the entry and between the 1050 and 950 stations it was also greater in the air course, being 298 feet per second as compared with 232 feet per second in the entry. In test 144 the tin

foil at stations E 1150 and A 1150 broke 3.59 and 6.01 seconds, respectively, after the ignition; the velocity thus indicated was too slow to raise a dense cloud of dust to continue the propagation. In test 151 the velocity between the 1150 and 1050 stations was 39 feet per second in the air course as compared with 92 feet per second in the entry. The flame died away in the air course before the 950 point was reached, but propagation continued in the entry.³⁶

In test 153 a mixture made of 30 parts coal dust and 70 parts shale dust and containing 72.8 per cent incombustible matter was distributed. Complete propagation was not obtained in the air course, but was obtained in the entry; the velocity, however, was very low in the 100 feet between the 1150 and 1050 stations, being only 25 feet per second, and the tin foil at station E 950 was not fused, although the matches were burned. Thus the flame would probably have died away had the zone been longer. In the air course the flame extended as indicated by the matches, to the A 1000 point, or 300 feet from the coal-dust zone, but the tin foil at station A 1150, 150 feet outby the coal-dust zone, was not fused.

Tests 299 and 306 were also made with a mixture of 30 parts coal dust and 70 parts shale dust, the dust being distributed at rates of $1\frac{1}{2}$ and $3\frac{1}{2}$ pounds per foot, respectively. Propagation was obtained in both tests, but with slower velocities in the latter test.

Five tests were made with mixtures of 25 per cent coal dust and 75 per cent shale dust, no gas being present in the air current. Propagation was obtained in only one of these tests, No. 264, in which a mixed dust distribution of 4 pounds per foot was used. Propagation was almost obtained in test 300 with a mixed-dust distribution of 2 pounds per foot; in this test the flame did not quite reach the end of the entry zone, but this may have been due to the fact that this portion of the mine is usually damper than the rest of the explosion zone. Test 307, with the same conditions as No. 300, failed to give the same result. It is supposed that this mixture is so near the dividing line that changes in condition so slight as to be unnoticeable may have affected the results.

The results of tests 154 and 157 were much the same, the flame, as indicated by matches, extending from 100 to 125 feet outby the coal dust zone in the entry and 150 feet outby in the cut-through and air-course branch. The time of melting of the E 1150 foil was nearly the same in the two tests, being 7.05 seconds in test 154 and 6.87 seconds in test 157.

Test 268 was made with a mixture containing 20 per cent coal dust and 80 per cent shale dust; the flame did not extend beyond stations E 1100 or A 1100 in the respective entries.

³⁶ Differences of velocity in the entry and air course are probably due to relative movements of air and gas columns in the respective parallel entries connected at the face and acting as in a U-tube.

SUMMARY.

The results of this group of tests may be summarized by stating that propagation may be obtained in a dry zone, under favorable conditions, through a mixture containing 25 per cent pulverized coal dust and 75 per cent pulverized shale dust and having 76.4 to 77.8 per cent incombustible matter, but it can not be obtained through a mixture containing 20 per cent pulverized coal dust and 80 per cent pulverized shale dust and having an incombustible content of about 81.4 per cent, there being no gas in the ventilating current in either case. The foregoing conclusion has reference to Pittsburgh coal dust only.

COMPARISON OF PROPAGATION TESTS ON MIXTURES OF PULVERIZED PITTSBURGH COAL DUST WITH ROOF-SHALE DUST AND MIXTURES WITH PIT-SHALE DUST WITHOUT GAS IN THE VENTILATING CURRENT.

On comparing the series of propagation tests in which roof shale was used with the group in which pit shale was used, no gas being present in the ventilating current, it is seen that in both series propagation was obtained through a mixture containing 25 per cent coal dust and 75 per cent shale dust. With roof shale (see test 156) the percentage of total incombustible in the mixture was only 69.8, whereas with pit shale (test 264) it was 76.6. Propagation possibly might be obtained with a higher percentage of roof shale, but this was not tried. Summarizing, in each of the three tests with 70 per cent roof shale and the three tests with 70 per cent pit shale, there was propagation. With 75 per cent roof shales, of the two trials, one propagated. In the six trials with 75 per cent pit shale, two propagated feebly. One test with 80 per cent pit shale showed failure to propagate.

The two shales therefore have about the same value in preventing coal-dust explosions in spite of there being some combustible matter (9 per cent) in this particular roof shale. When compared on the basis of percentage of total incombustible the result is practically the same. The chief advantage of comparing the latter basis is because in analyzing the dust of a commercial mine it is impossible to distinguish between the ash and moisture of the coal dust and the ash and moisture of the natural impurity or of the rock dust used for preventing of explosions.

TESTS OF DUSTS WITH NATURAL GAS IN THE AIR CURRENT.

One of the important objects of the explosion investigations at the experimental mine is the determination of the increase in sensitiveness to explosibility of coal dust where fire damp or gas is present

in the mine air in small and in larger percentages less than the explosion limit of methane; namely, 5.5 per cent.

Inflammable mine gas or fire damp as it issues in "gas blowers" or "gas feeders" in the mine has been found to consist of almost pure methane.

As previously explained, that area of the Pittsburgh bed in which the experimental mine is opened is exposed by outcrops on all sides but the west and is so drained of "free gas" that none is detected in samples of the mine air by careful analysis. This condition was sought in selecting the site for the mine, in order that no uncertainty would arise in explosion tests of coal dust alone.

In order to test coal dust in combination with inflammable gas it was therefore necessary to introduce the gas into the mine air, usually at the fan, though for certain special tests of initiating explosions at the face the gas was introduced behind a diaphragm by the compressed-air pipe line.

CHARACTER OF GAS USED.

As manufacturing pure methane on a large scale would be difficult, and as a large supply of natural gas was available from a high-pressure main on the property, the natural gas was used. The average analysis²⁷ of the gas is as follows:

Average composition of natural gas used in tests.

	Per cent.
Methane.....	84.7
Ethane.....	9.4
Propane.....	3.0
Butane (chiefly).....	1.3
Nitrogen.....	1.6

Because of its ethane content the natural gas is slightly more sensitive than pure methane, the lower explosive limit in air being 5.2 per cent²⁸ as compared with 5.5 per cent for methane, but in proportions of less than 3 or 4 per cent there is no appreciable difference as regards the effect in a safety lamp. Likewise, the difference is believed to be inappreciable in large-scale testing with coal dust. In any event any slight increase of sensitivity would only place the warnings given by the results of the tests further on the safe side. Moreover, in a number of the important coal fields of the United States, as in the Pittsburgh district of Pennsylvania and in districts in West Virginia, Illinois, Indiana, Kansas, and Oklahoma, natural-gas leakage from wells into the coal beds is likely to be encountered;

²⁷ Burrell, G. A., and Oberfell, G. G., Composition of the natural gas used in 25 cities, with a discussion of the properties of natural gas: Tech. Paper 100, Bureau of Mines, 1915, p. 8.

²⁸ Clement, J. K., The influence of inert gases on inflammable gaseous mixtures: Tech. Paper 43, Bureau of Mines, 1913, pp. 7, 9; Burrell, G. A., and Oberfell, G. G., The limits of inflammability of mixtures of methane and air: Tech. Paper 119, Bureau of Mines, 1915, p. 25.

hence recommendations based on the use of natural gas are on the safe side. Accordingly natural gas was adopted for the standard in testing, and in this bulletin, unless otherwise stated, the term gas will be understood to mean natural gas.

RESULT OF TESTS.

The tests of the different dusts with natural gas in the ventilating current are all given under the proper series in different parts of this bulletin. The effect of small percentages of natural gas upon the explosibility of pulverized Pittsburgh coal dust under propagation test conditions is shown in the latter part of Table 17 (p. 170). All of these propagation tests were started by means of the standard 50-foot ignition zone, as described later on page 181.

Tests 199 and 200 were made with the ignition zone only, a dustless zone being prepared outby. An attempt was made to introduce 2 per cent of gas in both tests, the analyses showing 2.68 per cent in test 199 and 2.29 per cent in test 200. In test 199 the flame extended 85 feet beyond the dust zone in the main entry and 90 feet past the dust zone in the last cut-through and air-course branch. In test 200 the flame extended the same distance as in test 199. These records were obtained by the use of the photographic paper recorders.

On referring to test 376 (p. 170) it is seen that the ignition zone without gas gave a flame which extended 50 feet beyond the ignition zone. The use of about $2\frac{1}{2}$ per cent of gas caused the flame to extend an additional 35 or 40 feet. Therefore in tests with about 2 per cent of gas, in which the flame did not penetrate the mixed dust more than 75 to 100 feet, it can be assumed that the mixed dust had little or no effect on the extent of the inflammation.

In one test out of six, in both entries propagation was obtained through a mixture of 25 per cent pulverized Pittsburgh coal dust and 75 per cent pulverized pit-shale dust without gas; another test (No. 300) gave propagation in the air course, but not in the entry. Test 158, with the same mixture and 0.95 per cent gas in the air current, failed to give propagation, although propagation might have been expected. The failure may possibly be attributed to the quenching effect of sand and cement particles abraded from the newly cemented walls and roof. In test 329, given in Table 19, the mixture of 25 per cent Pittsburgh coal dust and 75 per cent pit-shale dust was used, but the dust was of a size coarser than pulverized. One and four-tenths per cent of gas was used in this test. Propagation was obtained; consequently there can be no doubt that this mixture would propagate if pulverized dust were used and if 1 per cent or more of gas were present.

In order to neutralize the effect of the gas, additional shale is necessary. Test 324 was made with 20 per cent pulverized coal dust and 80 per cent pulverized shale dust, using 1.1 per cent natural gas in the air current. Propagation was not obtained in this test, the flame extending about halfway through the test zones. When the content of gas was raised to 1.7 per cent, in test 323, propagation was obtained with this mixture.

SUMMARY OF PROPAGATION TESTS WITH MIXTURES OF PULVERIZED PITTSBURGH COAL DUST AND PULVERIZED PIT-SHALE DUST.

In summary, the propagation tests with pulverized Pittsburgh coal dust and pit-shale dust show that propagation will be obtained but rarely with a mixture containing 25 per cent pulverized coal dust and 75 per cent pulverized pit-shale dust, or a ratio of coal dust to shale dust of 1:3, where there is no gas in the ventilating current, but that propagation will be obtained with a mixture containing 20 per cent pulverized coal dust and 80 per cent pulverized shale dust, or a ratio of coal dust to shale dust of 1:4, when there is 1.7 per cent gas in the ventilating current.

It did not seem to be of practical mining value to use, for explosion prevention, shale dust in excess of four times the amount of fine dust—corresponding with pulverized dust—unless the amount of such dust is kept to a minimum. If four pounds of shale dust per linear foot of entry is about as much as is practicable to use, this means that the amount of fine coal dust must be kept well below 1 pound per linear foot; but the remedy is obvious, namely, not to permit men to work in places containing such percentages of gas, whether or not coal dust is present in large or small amounts.

EXPLOSIBILITY CURVES SHOWING THE EFFECT OF SMALL PERCENTAGES OF NATURAL GAS IN THE VENTILATING CURRENT.

Figure 27 shows the increase of incombustible content in a dust mixture that is necessary to prevent propagation when there is a small percentage of gas present in the air current.

As the explosibility of a coal dust can not be measured directly, some arbitrary standard must be adopted for measuring this factor. Throughout this bulletin the explosibility of any given coal dust is measured by the total amount of incombustible present in the mixture of coal dust and inert dust that will prevent an explosion under the standard conditions of ignition tests or propagation tests, as the case may be.

By referring to the lower curve, defined by plain symbols, in figure 27, which shows the explosibility of pulverized Pittsburgh coal dust in the ignition tests, the reader will see that with no gas in the venti-

lating current the total incombustible content of the mixed dust must be 65 per cent or more to prevent ignition. The hollow symbols represent the conditions for those tests in which ignition was not obtained. For instance, in test 175 the mixed dust contained 64 per cent of incombustible and ignition was obtained. On the other hand, in test 180, with the same mixture, ignition was not obtained.

On following the curve to the right the reader will note that in test 222, in which 1.1 per cent gas was used, ignition was not obtained

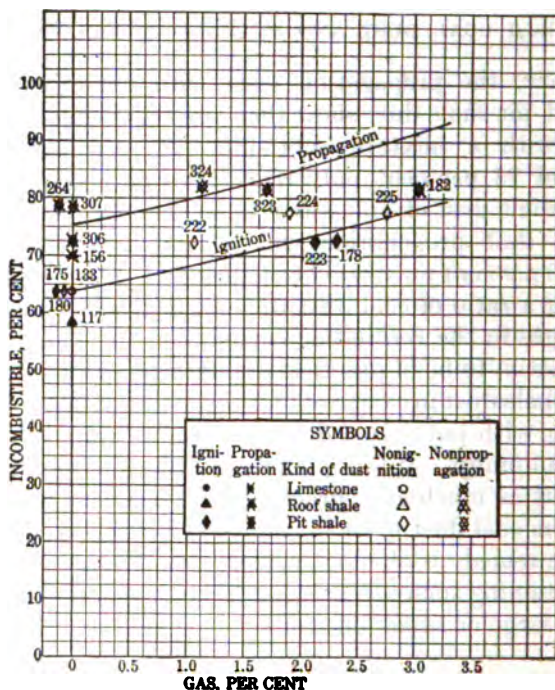


FIGURE 27.—Curves showing effect of small percentages of gas in the ventilating current on explosibility of mixtures of pulverized Pittsburgh coal dust and various incombustible dusts. Figures near symbol denote test numbers.

with a mixture containing 72 per cent incombustible. Likewise ignition was not obtained in test 224, using 1.9 per cent gas, with 77 per cent incombustible, but was obtained in test 223 with a mixture containing 72 per cent incombustible when 2.1 per cent gas was used in the air current.

Following the curve still further to the right, one notes that in test 225 ignition was not obtained with a mixture containing 77 per cent incombustible and using 2.75 per cent gas in the air current.

For standard ignition tests, then, that region above the lower curve represents conditions of nonexplosibility, whereas the region below the curve represents conditions of explosibility or danger.

The explosibility limits of the pulverized Pittsburgh coal dust in propagation tests are shown in the upper curve (fig. 27), which is defined by symbols having an X superimposed on them. It will be noted that propagation was obtained in test 323 with 1.7 per cent gas, in a mixture containing 81 per cent incombustible.

STANDARD TEST METHODS.

As a result of the many series of tests described in the previous pages a standard method for testing dusts from different kinds of coal from various parts of the country was adopted. This method is described below. It is realized that the methods used do not duplicate the conditions in any one mine from which coal samples were obtained for testing. However, in order that the effect of any one factor may be accurately determined it is necessary that all other conditions be held as nearly constant as possible. The conditions chosen for tests were those that could be duplicated easily for all tests. They were also intended to represent the most dangerous conditions that might be found in operating mines, because any safety methods advocated as a result of these tests must be adequate for meeting such conditions.

SPECIFICATIONS OF STANDARD IGNITION TEST METHOD.

In accordance with the plan of testing finally adopted, and as explained on page 76, two classes of tests are made, called ignition tests and propagation tests. The specifications of the standard ignition test are as follows:

1. An explosion zone is prepared that extends from the cannon at the face of the main entry, station E 1300, outby for a distance of 350 feet in the main entry to station E 950, and also, beginning at a point 50 feet from the face, for a distance of 50 feet through the last cut-through and 300 feet outby along the parallel entry or air course to station A 950.

2. The mixture of coal dust and shale dust to be tested is distributed at such a rate that the coal dust in the mixture amounts to 2 pounds per linear foot of entry, except that the maximum loading never exceeds 5 pounds of mixed dust per foot. In some of the later tests the amount was reduced to 1 pound of coal dust per linear foot.

3. The surfaces of the test zone, which are concrete lined, are thoroughly cleaned, usually with jets of compressed air, to remove as completely as possible the dust left from the previous test. The fresh dust is placed on side shelves, cross shelves, and the floor, and to a less extent is thrown on the upper surfaces in order to accomplish as wide a distribution as possible

4. After distribution of the dust, samples are taken for analysis to check the attempted percentages of coal and shale dust.

5. When gas is used, four samples of the mine air are taken for analysis immediately before firing.

6. A blown-out shot of 4 pounds of FFF black blasting powder, stemmed with 3 pounds of slightly damp fire clay, is then fired into the mixture from a cannon at the face of the main entry.

7. The explosion is stopped at the end of the explosion zones in the air course and entry by some form of rock-dust barrier.

If the cannon shot ignites the dust and the flame is propagated to the ends of the explosion zones in the two entries, ignition is said to have been obtained. If the flame does not reach the end of the zones, it is said that ignition has not been obtained. Oftentimes the flame may be 100 or 200 feet long, but fail to reach the end of the zone, because the dust mixture was not inflammable enough in air to sustain an explosion beyond the influence of the cannon blast or because the starting impulse was not strong enough, just as a weak detonator may fail to detonate all of a charge of dynamite, leaving unexploded sticks. In order to cover the possibility of the starting blast being very strong, and because in mines a strong start might be given by a group of large shots fired together or by ignition of a body of fire damp, the plan of a so-called propagation test was devised.

PROPAGATION TEST METHODS.

The ignition tests were made to determine the lowest percentage of rock dust or inert matter in the coal-dust mixture that will prevent the initiation of an explosion by the direct effect of a blown-out shot. However, an explosion might start at the face of an entry that had not been treated after coal had been blasted down and fresh dust made, or in a room that was not treated, and might attain a relatively high velocity and strong pressures before the explosion reached a treated zone. This possibility brought up the point as to whether a relatively strong explosion on entering a treated zone could sustain itself through dust in which an explosion could not be initiated, just as a strong detonator will completely explode a string of dynamite sticks when a weak detonator would fail to do so. It was found that there were mixtures in which an explosion could not be started by the standard igniting arrangement but which would permit propagation of an explosion already well under way, often with increasing pressures as the explosion advanced through the zone.

In determining this point explosions were started in zones of pure Pittsburgh coal dust 50, 100, and 300 feet long, and the mixtures with the highest percentage of shale that would permit propagation were determined. It was found that as effective a starting impulse was given by a 50-foot zone of pure Pittsburgh coal dust impinging

into a double-entry zone of the dust under test, employing cross shelves in loading, as was given by a 300-foot coal-dust zone in a single-entry zone with an open dustless cut-through and air course. Hence the former arrangement was adopted as the standard starting zone for propagation tests, since it was easier to prepare, and, moreover, the results in the air course and entry with their separate zones gave checks on each other. The initiation of propagation tests by a measured volume of fire damp was tested as described later, but was abandoned on account of the difficulties and hazards involved as compared to a cannon shot and a pure dust zone of 50 feet.

IGNITION ZONE OF PURE COAL DUST.

The manner of loading the first 50 feet outby the cannon, or the ignition zone, is to distribute pulverized Pittsburgh coal dust at the rate of 2 pounds per linear foot, with an additional 25 pounds on the bench in front of the cannon, and the explosion is originated by firing the standard blown-out shot into it. The effect of an explosion in this 50-foot zone of Pittsburgh coal dust is roughly equivalent to that of an explosion of a 50-foot body of explosive gas as described below or to an explosion in a longer zone of a coal dust less sensitive to explosion.

Tests 191, 198, and 376, shown in Table 17 (p. 170), were made with the ignition zone only, the remainder of the concreted entries being carefully cleaned. The flame extended only 25 to 50 feet beyond the outby end of the dust loading in the ignition zone, as shown by the photographic flame indicators. The pressures were 1 pound per square inch. Therefore, if in a propagation test without gas the flame extends more than 50 feet beyond the end of the ignition zone it must have been assisted by the dust under test in the outby zones.

IGNITION ZONE OF EXPLOSIVE MIXTURE OF GAS AND AIR.

Tests 167 and 176 were made to determine the length of flame caused by igniting an explosive mixture of gas and air confined in the inner 50 feet of the main entry, behind a paper diaphragm. A measured quantity of natural gas was passed through a meter and through the diaphragm, the air being allowed to escape through a small hole in the paper near the floor. After the desired quantity of gas had been admitted the hole in the paper was sealed up and the gas and the air were mixed by a motor-driven fan, controlled from the outside of the mine. After mixing was completed the mine was again entered and samples taken through pipes from various points in the 50-foot zone. The samples taken in test 167 indicated an average mixture of 7.70 per cent gas, whereas nine samples taken in test 176 range from 8.90 to 9.70 per cent gas. An air current was coming

through the 1250 cut-through and passed the diaphragm during the entire time that the gas was being fed in, while it was being mixed, and while samples were taken. Whatever gas may have leaked out from behind the diaphragm, therefore, would have been much diluted and carried out of the mine with the air current, so that at the time when the gas was ignited there would be little or no gas in the ventilating current of the mine. The gas was ignited by the simultaneous shooting of two black powder igniters and a No. 6 detonator at different points in the gas zone.

The flame from the ignition of the gas mixture extended to the point E 1175 in test 167 and to E 1225 in test 176, 75 feet and 25 feet, respectively, outby the diaphragm. Pressures were not obtained within the 50-foot zone but in test 167 the pressure was 7 pounds per square inch, 150 feet away at A 1150. The record at E 1150 was uncertain. As the flame in this test did not go as far by 50 feet as in test 176, in which the instruments failed to operate, it is presumable the pressure was less than in 176. With the opportunity of expanding sixfold and the cooling of the walls, it is probable the pressure within the gas zone at the moment of explosion was not more than 50 pounds per square inch. It was found that the coal-dust ignition zone does not give a more severe starting explosion for testing propagation limits than does the zone of an explosive mixture of gas and air.

PROPAGATION ZONE.

The manner of loading the dust in the propagation tests is the same as in the ignition tests, outby the ignition zone. If the explosion started in the coal-dust ignition zone continues to the ends of the test zones in the two entries, the mixture is said to have propagated. The use of the pure Pittsburgh coal dust in the initiating zone permits the giving of a uniform starting impulse in testing various kinds of more or less inflammable dusts.

USE OF GAS IN STANDARD TESTS.

No coal mines are free from the possibility of encountering methane or, it may be, natural gas. In some coal mines the amount of gas may not be enough to be appreciable, but in fully 75 per cent or more of the producing mines in the United States the liberation of gas in some working place is an every-day possibility, even in so-called nongaseous mines, and is an acute problem in hundreds of mines. Accordingly, as part of the standardized testing, natural gas is introduced into the air current in predetermined percentages in some tests. The exact percentages can not be arranged, but by sampling the air at different points in the mine just before firing, the percentage actually present at the time of testing can be determined. The procedure is as follows:

GENERAL PROCEDURE.

If a certain mixture does not ignite or propagate without gas, a small percentage of natural gas is intimately mixed with the air current by admitting the gas through the fan, used as a blowing fan. Usually 1 per cent gas is tried first. If this gives ignition, the percentage of shale dust is increased 10 per cent. If the higher shale dust mixture will not ignite with 1 per cent gas in the air current, then the gas percentage is increased to 2 per cent. The same procedure is continued until, if there is sufficient dust, the following information is obtained: The mixtures with the lowest percentages of shale dust that will prevent ignition with no gas present, with 1 per cent gas in the air current; also with 2 per cent gas in the air current, respectively, are determined, and the mixtures that will prevent propagation with no gas present, with 1 per cent gas present, and with 2 per cent gas present, respectively.

With some insensitive dusts or dust mixtures 3 per cent of natural gas has been employed in the tests to establish limits. The data thus gathered have been used in the construction of curves of limits, which enable the interpolation of limiting points for various percentages of coal and inert matter.

DETAILS IN EMPLOYMENT OF GAS IN DUST TESTS.

In the gas tests natural gas, having a composition of about 85 per cent methane and 15 per cent ethane and other hydrocarbons, is released from a supply pipe into the intake of the ventilating fan. The whirling action of the fan tends to mix intimately the gas and air. The air current is kept as constant as possible by running the fan engine at constant speed and by having the intake door open only a slight amount, to prevent, as far as possible, variations due to gusts of wind. The gas content is estimated in a preliminary way by observing gas caps on a Wolf type of safety lamp with round wick; the volume of gas entering the fan is regulated by a valve at the gas meter, in accordance with instructions from the gas inspector. As soon as the lamp reading seems to be correct a sample is taken in a small portable methane-analysis apparatus and the methane percentage determined. If the analysis is satisfactory, the inspector passes through the mine, testing at various points to determine whether the same percentage prevails through the explosion zone. When the lamp readings throughout seem satisfactory, final gas samples are taken at four points in the zone, the men are withdrawn from the mine, and the shot is fired as soon as possible. Usually about five minutes elapse before the shot is fired, this time being required for the warning signals and the final adjustment of recording apparatus. The final samples are carefully analyzed in the laboratory by the standard evacuated-tube method.

After some practice, under the uniform mine conditions, it has been found possible to estimate the gas percentage by the safety lamp, using a turned-down wick, within about 1 per cent, and the percentage can be estimated very closely as low as three-fourths of 1 per cent. It required from one hour to one and one-half hours from the time the gas is first turned in to get a uniform condition throughout the mine. At times considerable difficulty was encountered in keeping the percentage constant after it had once been obtained, particularly on windy days when the direction and velocity of the wind was erratic and caused changes in the quantity of air going through the mine. Occasionally the actual percentage present, as determined by final sampling, differed decidedly from that attempted, the difference being principally due to variations in wind conditions affecting the intake and the return.

CLEANING THE MINE.

After each explosion test in the mine the cement-lined explosion zone is carefully cleaned before the dust for the next test is taken in. The first step consists of sweeping the residue from the shelves and then sweeping the floor of the entries. Then a careful cleaning with a compressed-air jet follows, the air current being maintained at a high enough velocity to carry out the dust as it is raised from the surfaces. Extreme care is taken to see that practically every square inch of all surfaces is covered by the air jet. This operation generally requires about 16 hours for the 750 feet of cement-lined test zone. Just before the fresh dust for the next test is taken into the mine, the zone is again gone over very carefully with soft paint-brushes and push brooms to remove any small accumulations of dust that may have been overlooked in the cleaning with compressed air. The entire zone is inspected very critically, using a powerful flash-light, to be sure that not the slightest trace of dust remains.

DISTRIBUTION OF DUST.

The dust to be tested is brought into the mine in covered metal cans which contain a known weight of dust. The spacing of these cans is carefully measured and care is taken to distribute the dust from any one can over only the measured space for that particular can. The dust from a can is divided carefully into three parts in the proper portions; one part is distributed upon the overhead cross shelves through the measured zone for that can; a second part is distributed over eight 3-inch side shelves, four being on each side in the entry, and the remaining part is distributed uniformly over the floor. During warmer weather, when occasionally there are wet spots on the floor, no dust is placed on such wet spots. If the spots are small they are avoided in spreading the dust, but if a spot

is large it is covered with dry boards and the dust is placed upon these boards. This method of distribution insures that practically all of the dust is free to be raised into the air by the force of the advancing explosion.

SIZES OF DUST USED.

The coal dust used in the explosibility tests is ground in the grinding house at the experimental mine from run-of-mine coal. The coal is first crushed in a hammer crusher having a screen with $\frac{1}{8}$ -inch slots in it. It is then passed through a pulverizer which has beaters revolving at a very high velocity. The fine material is elevated by an air current to dust collectors, from which the dust is drawn off as needed. The strength of the elevating air current can be modified by changing the size of the inlet openings, thus regulating the size of the dust particles that are carried out. Early in the series of tests a definite size of inlet opening was adopted, and this size was used in the preparation of the dust used. Only occasionally was any change necessary to insure about the same percentage of fine sizes in the various dusts tested. In some of the tests the dust was used as it came from the crusher, no pulverizing being done. In still other tests some of the pulverized dust was mixed with the coarse dust in such proportions that the mixture would have a certain predetermined percentage of 200-mesh dust. The shale dust used in any particular test was generally prepared similarly to the coal dust for the same test.

MIXING AND DISTRIBUTION OF DUST IN STANDARD TESTS.

The coal dust and shale dust are weighed out in such relative proportions that a mixture is given having the percentages desired for the test planned. A total of 50 to 100 pounds of the two constituents are placed in a chamber of a mixing apparatus consisting of a metal can with a dust-tight cover, which is then revolved for a sufficient number of turns to mix thoroughly the constituents. The dust is then dumped from the mixing chamber and a known weight shoveled into cans. The covered cans, each containing about 150 pounds of dust, are taken into the mine and placed at measured intervals. Usually the mixing and distribution of dust take place the same day the test is made.

SAMPLING OF DUSTS.

Samples of each size of the coal dust and shale dust used are taken before the dusts are mixed. Screen tests and analyses are made of these samples. Two or more samples of the mixed dust are taken from the shelves in the mine just before firing the igniting shot and are analyzed to determine whether the mixture as actually tested is the same as that planned. The analyses were made at the Pittsburgh

station under the direction of A. C. Fieldner, in charge of the chemical research laboratories. Most of the screening tests were made at the experimental mine; in the earlier tests the screens were shaken by hand but later the screens were shaken by a mechanical shaker.

Some trouble was encountered in determining the percentage of 200-mesh dust. Three screens, all nominally 200-mesh, were used during the test period. Screen A, used during the early part of the period, was later found to have holes larger than the standard size, and Screen B was found to have holes too small. A third screen, C, was obtained later which was tested and found to be correct and was used as the standard in all subsequent tests. The results with all three screens are given for some of the dust, and from this, comparison of the three screens can be made and some idea gained of the probable error in the early series in which only the A screen was used or in those tests where the B screen was used.

CHAPTER V.—EXPLOSIBILITY TESTING OF DIFFERENT-SIZED PITTSBURGH DUSTS.

PRELIMINARY CONSIDERATIONS.

In making determinations of the relative explosibility of the dusts of various kinds of coal, finely ground or pulverized dust has generally been used. The percentages of fine sizes—that is, of dust passing through 100-mesh and 200-mesh screens—vary only slightly in the pulverized dusts, so that variations in results of tests are principally due to other factors affecting the explosibility. It was recognized in the course of these investigations that the relative behavior in an explosion of dusts pulverized by machinery was not necessarily identical with the behavior of dusts from the same coals made incidentally in mining operations; that is, in mining operations all coals do not break alike. Some coals, like the subbituminous and splint coals, tend to break cubically and do not make fine dust, whereas other friable coals, like the smokeless coals of West Virginia, make much fine dust. This condition is reflected in freedom from disastrous explosions of some mining districts as in those first named, while many explosions have in the past occurred in districts in which friable coals are mined. When the coal dust is produced by crushers and grinders or pulverizers, the natural structure of the coal fragments is broken down, and the coal dusts thus produced are highly explosive, like the pulverized dust of subbituminous coals, and the relative behavior of the various pulverized dusts depends, as will be hereinafter indicated, on characteristics other than the structure, such as content of volatile combustible and the ash and moisture ratios.

Accordingly after standard methods had been determined upon, using pulverized dust, it was considered necessary to make tests upon dusts of different natural sizes, first of Pittsburgh coal and subsequently of dusts of various coal beds in different mining districts.

The reader who compares the explosibility limits and effects produced in these experimental mine tests with those obtained by foreign stations, must bear in mind that size of dust is one of the most important factors and as between different kinds of bituminous dusts, is the most important factor.

WHAT CONSTITUTES COAL DUST.

In the comparison of naturally or incidentally made dusts of coal mines it is first essential to know what constitutes dust, and particularly coal dust. This question was considered in Bulletin 20⁵⁹ under

⁵⁹ Rice, G. S., and others, The explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, p. 33.

the heading "Coal dust and its origin and distribution," wherein it is stated: "Coal that will pass through 100-mesh screens is frequently accepted as representing mine dust." Tests were made in the Pittsburgh gallery "to determine how coarse coal dust could be and yet propagate an explosion. The tests were made successively on pure coal dusts in four sizes: (1) Through 80 and over 100 mesh; (2) through 60 and over 80 mesh; (3) through 40 and over 60 mesh; (4) through 20 and over 40 mesh. The fine dust made by abrasion in the process of screening and handling was floated off by stirring with a jet of compressed air. The results showed ready propagation of sizes (1), (2), and (3) and partial propagation of (4); the belief was expressed that, according to the indications, propagation of (4) might have been obtained with a larger initiating charge than that used (2½ pounds of black powder). Accordingly the senior author, in charge of the investigation, recommended tentatively that 20-mesh be accepted as the dividing line between fine coal and dust, and stated: "It must not be inferred that larger particles of coal may not be a factor in a mine explosion once fairly started. The assumption as to the size (20-mesh) therefore refers only to the initial stage of an explosion."

It should be noted also that in the tests referred to the finer sizes of coal dust were excluded in each test, whereas if the fine dust were included it is probable that dust coarser than 20-mesh might be a factor in a strong, prolonged explosion in which coarse dust might be carried along in the active combustion zone.

The term "combustion zone" is here used in the sense of a fast-moving flaming body that constitutes the constantly progressing locus of violent chemical reactions of any individual branch of an explosion, traveling through a mine entry or a room filled with air, dust and gases.

In the tests at the experimental mine on the influence of different sizes of dust on their relative explosibility it was therefore deemed best to include the several screen sizes in any one sample up to the maximum screen size selected for the particular test.

ADOPTION OF 20-MESH AS COARSEST LIMIT FOR DUST TESTING.

It was decided in beginning this series of tests to try coal particles as large as would pass through a screen with 1-inch square openings. Later it was found that for the length of the standard test zone particles larger than those passing through a 20-mesh wire screen (openings between wires about 1/30 inch square) had no appreciable influence upon the explosions, so 20-mesh dust was accepted as the upper or larger limit in the size of dust. Any particles over this size

⁶⁰ Rice, G. S., work cited, p. 42.

was rejected in making subsequent standardized tests of explosibility. It became evident from screening tests that in artificially prepared dust—that is, dust made by pulverizing machinery—the percentages of the different screen sizes finer than the coarsest size included in the sample under test varied, even with dust of the same kind of coal; the variation was probably due chiefly to differences in the time of exposure in the grinding and pulverizing machines, but also to variations in conditions of the machines. Accordingly it became evident that numerous road-dust and rib-dust samples of different mine dusts should be gathered in order to determine the average proportion of each smaller size, so that artificially made dust, prepared from the large coal sample from that mine, be made to conform as nearly as possible in respect to the proportions of fine sizes therein for the primary explosion testing. Later, in each series of tests relating to the particular mine, specific quantities of rock dust were added successively until ignition or propagation, as the test might be, was no longer obtained, thus fixing what is termed the limits of explosibility for those dusts.

A large number of samples were gathered from Illinois mines for sizing tests.⁴

After discarding the dust coarser than 20-mesh, the average of the remaining finer sizes showed 37.2 per cent through 100-mesh and 25.3 per cent through 200-mesh for the road samples. The average for the rib samples was 44.8 per cent through 100-mesh and 31.1 per cent through 200-mesh. The curves of these average values are shown in figure 28.

Figure 29 shows how nearly one of the standard sizes adopted for testing in the mine agrees with a single sample taken from one of the Illinois mines. The curve on the right is for the mine sample and that on the left is the dust prepared for test at the experimental mine. The curves are very close together for the fine sizes, which are the most important. The coarser sizes, where the curves separate slightly, are of relatively less importance.

As any dust or mixture of dusts consists of different proportions of each of the various sizes present, even when all the dust will pass

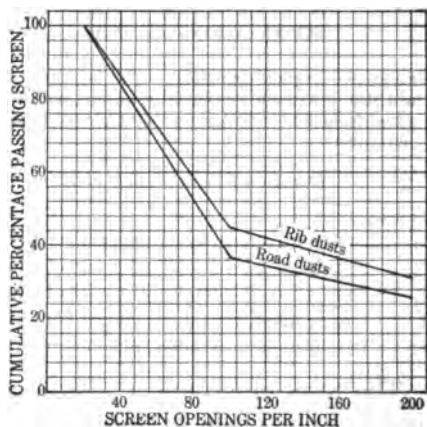


FIGURE 28.—Average sizing test curves for road and rib dusts from 100 Illinois mines.

⁴ See Clement, J. K., and Scholl, L. A., Jr., *The inflammability of Illinois coal dusts*: Bull. 102, Bureau of Mines, 1916, 74 pp.

through a given screen, such as the 20-mesh, it was found advisable to choose one of the smaller sizes to indicate the proportion of the finer and more dangerous sizes in the 20-mesh mixture. After explosion tests with many combinations of sizes it was found that the 200-mesh dust was the best indicator of the sensitiveness to explosibility, so throughout the later work with 20-mesh dust its degree of fineness is designated by the percentage of 200-mesh dust present.

The 200-mesh sieve has a width of opening of 0.0029 inch between wires. The method of expressing the size of dust under test is shown by the following list of tests, the results of which are described as follows:

FIGURE 29.—Average sizing test curves for a standard size of 20-mesh Pittsburgh coal dust, as prepared for explosion testing, and a sample of Illinois mine dust.

Results of sizing tests, showing method of expressing size of dust.		
Group.	Size.	Number of tests.
1.	20-mesh coal dust, 40 per cent of which passes through 200-mesh.....	17
2.	20-mesh coal dust, 20 per cent of which passes through 200-mesh.....	10
3.	20-mesh coal dust, 10 per cent of which passes through 200-mesh.....	12
4.	$\frac{1}{2}$ -inch mesh coal dust, 20 per cent of which passes through 200-mesh.....	12
5.	1-inch mesh coal dust, about 2 per cent of which passes through 200-mesh.....	5

The tests of groups 4 and 5 were made prior to the selection of 20-mesh as the coarsest limit.

The screen analyses of the dusts adopted as standard for the explosion tests in the experimental mine are illustrated graphically in figure 30. For purposes of comparison the average screen tests of the large number of Illinois mine, road, and rib dusts are also plotted. The curves for the standard sizes for the tests in the experimental mine are plotted with solid lines. The curves for series in which $\frac{1}{2}$ -inch coal 20 per cent of which would

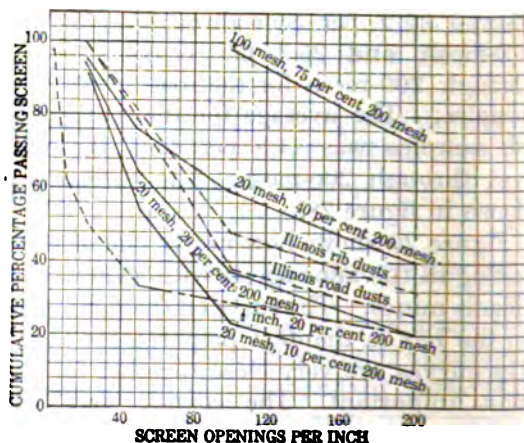


FIGURE 30.—Sizing test curves for standard sizes of 20-mesh Pittsburgh coal dust, as prepared for explosion testing, and average sizing test curves for Illinois mine dusts.

The curves for series in which $\frac{1}{2}$ -inch coal 20 per cent of which would

pass through 200-mesh was used is plotted as a dot-and-dash line. The curves for the two groups of tests with Illinois dusts are plotted as dotted lines. A study of this figure shows that the Illinois road dust approximated very closely the standard size of 20-mesh dust having 20 per cent finer than 200-mesh.

After preliminary testing of coarse dusts of various sizes the arrangements for testing 20-mesh dusts of different kinds were standardized. The tests first made were propagation tests, in which standard ignition zones, 50 feet long, of pulverized Pittsburgh coal dust were used. Propagation tests were made first as the bureau's engineers considered it less important to know the lowest percentage of incombustible in the mine dust that would prevent an explosion from originating than to know the lowest percentage that would not sustain propagation of an explosion already in progress. In an active coal mine there is always the possibility that in the active working places fresh untreated coal dust or a pocket of gas may be ignited and start an explosion.

Later, standard ignition tests were made on two of the standard sizes of 20-mesh dust. These tests are also described in this chapter.

EFFECT OF QUANTITY OF DUST ON IGNITION AND PROPAGATION.

The quantity of coal dust that must be present to propagate an explosion has been studied by many investigators at the testing galleries in different countries. This subject was discussed in Bulletin 20,⁴² and some tests were made in the Pittsburgh gallery which indicated that as little as 0.0317 ounce of pure 200-mesh Pittsburgh dust per cubic foot of gallery (equivalent to 31.7 grams per cubic meter) would propagate an explosion. Taffanel, the French investigator, obtained one propagation in preliminary tests in the small experimental gallery at Liévin (1907) with as little as 23 grams of coal dust per cubic meter, but to obtain explosions with regularity he found it necessary to use 70 grams per cubic meter.⁴³

It seemed advisable to make tests of the quantity needed under the conditions found in a mine entry. The density of loading the coal dust and the size of the dust particles are evidently so closely related in their influence on the explosibility of the dust of a particular coal that the problems can not be considered independently. For example, in the Pittsburgh gallery a distribution of 32 grams of coal dust of 200-mesh size per cubic meter of gallery caused propagation when ignited by the flame of a blown-out shot. It is almost self-evident that had the same quantity of 20-mesh dust been used propagation would not have ensued, for the following reasons:

1. The 20-mesh dust would not mix so readily and thoroughly with the air on account of the weight of the coarser particles.

⁴² Rice, G. S., and others, The explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, p. 33.

⁴³ Rice, G. S., Work cited, p. 40.

2. It can be demonstrated mathematically that the aggregate surface of all of the particles of the 20-mesh dust would be far less than the aggregate surface of the same weight of 200-mesh dust; hence there would not be so much surface for instantaneous oxidation.

3. The number of particles in the 20-mesh dust is far less than in the same weight of 200-mesh dust; it is therefore probable that the individual particles in the dust cloud would be separated so widely that transference of flame from particle to particle would be prevented.

The foregoing statements indicate that the larger the size of the coal-dust particles the greater must be the quantity of dust in a given space to permit propagation of an explosion.

In the discussion "quantity of dust in a unit of space" is used synonymously with distribution or loading of dust per linear foot of entry or passageway, but it is not intended to mean that all the dust is raised into the air and mixed as a uniformly dense cloud by the advance air and gas waves and the eddy currents from the explosion. In most tests there is a large excess of coal dust over the amount that can be consumed by the oxygen present, but whether the quantity of dust is more or less than the quantity thus needed—which for pure Pittsburgh coal dust completely burned is 0.123 ounce per cubic foot (123 grams per cubic meter)—it is improbable there is complete and even mixing of all the dust and gases in the air at the moment of explosion combustion. Unfortunately there is no means of obtaining the density of the dust cloud at the moment the explosion flame reaches a given space. Attempts were made to obtain the density of a dust cloud in the Pittsburgh gallery, as described on page 41 of Bulletin 20. The dust was distributed by compressed air, and a fan was used to maintain circulation. The dust-laden air was sampled by drawing a certain quantity through a tube equipped with a dust filter, the sampler being started at the moment of injecting the dust. With the smallest coal-dust loading that propagated an explosion (0.0317 ounce per cubic foot of gallery) there was only 0.00275 ounce per cubic foot, or one-twelfth of the total loading in the air sample obtained. The dust was of the finest character, all passing through a 200-mesh sieve; coarser dust would be much more difficult to keep in suspension. Therefore it is evident that the eddying of the advance air currents of an explosion is far more effective in prior mixing of the dust than any mechanical arrangement, yet even the explosion blast leaves the larger part of the dust loading unchanged chemically. Many tests, some of which have been described under propagation tests of Pittsburgh pulverized coal dust, were made with different weights of dust loading per foot of entry to determine the effect of this factor.

When small dust distributions were made, it had been the practice to divide the dust per linear foot of entry about equally between cross

shelves, side shelves, and floor. When the heavy distributions were made, this practice could no longer be followed because there would have been too much dust on the side and cross shelves, thus impairing to a great extent the approximation to actual mine conditions. The dust was therefore distributed on cross shelves at the rate of 1 pound per foot of entry and on side shelves at the rate of 1.5 pounds; the balance, whatever it might be, was distributed along the floor.

IGNITION TESTS OF COARSE PITTSBURGH COAL DUST PASSING THROUGH 1-INCH SCREEN.

The purpose of these tests was to determine the smallest loading of very coarse coal dust (through a 1-inch screen) with which ignition could be obtained.

The tests were made with coarse Pittsburgh coal dust prepared by breaking lump coal by hammer and screening through a 1-inch mesh wire screen. The screen test on this material was as follows:

Results of screen tests of coarse Pittsburgh coal dust.

Average of tests 226 to 229.		Test 230.	
	<i>Per cent.</i>		<i>Per cent.</i>
Through 1-inch.....	100. 0	Through 1-inch.....	100. 0
Through 20-mesh.....	11. 89	Through 4-inch.....	65. 89
Through 50-mesh.....	5. 76	Through 4-mesh.....	29. 84
Through 80-mesh.....	4. 36	Through 10-mesh.....	13. 73
Through 100-mesh.....	3. 56	Through 20-mesh.....	a 8. 50
Through 200-mesh.....	2. 54	Through 48-mesh.....	4. 26
		Through 80-mesh.....	2. 76
		Through 100-mesh.....	1. 97
		Through 200-mesh.....	1. 78

a Interpolated from curve.

The tests were made with short zones in order to conserve material until the explosibility limit was approached. The zone in the entry was 100 feet long, extending from E 1300 to E 1200, additional dust being placed in the 1250 cut-through. Dust was distributed on cross shelves, side shelves, and on the floor where it was dry.

The following table shows the loading per linear foot in each test and the length of flame resulting:

Loading used and length of flame obtained.

Test No.	Loading (pounds per linear foot).	Length of flame.	
		By match.	By bromide paper.
226	2	<i>Feet.</i> 25	25
227	4	50	50
228	6	75	a 75
229	8	75	75
230	10	125	150

a At 1,225-foot point; faint.

It required a distribution of 10 pounds per foot to permit propagation of flame to the end of the 100-foot zone. Inasmuch as the zone was within the influence of the cannon, it would probably require a greater loading to permit ignition throughout a 300-foot zone.

In a 10-pound loading the weight of 20-mesh dust was only 0.85 pound, of the 100-mesh dust about 0.20 pound, and of 200-mesh dust 0.175 pound per foot of entry, equal to 0.05 ounce per cubic foot of space.

PROPAGATION TESTS WITH PITTSBURGH COAL DUST OF $\frac{1}{2}$ -INCH SIZE.

A series of 12 propagation tests was made with Pittsburgh coal dust of $\frac{1}{2}$ -inch size, the distribution varying from one-half pound to 6 pounds per foot of entry.

THE COAL DUST.

The dust was prepared by crushing run-of-mine coal in a hammer crusher equipped with a plate having 1-inch holes. About 97 per cent of the product obtained was material which would pass through a $\frac{1}{2}$ -inch screen; for convenience this material was designated $\frac{1}{2}$ -inch dust. In order that the coal dust tested might have about the same percentage of fine dust present in each test of the series, screen tests were made on the $\frac{1}{2}$ -inch dust and on pulverized dust, and these were then mixed in such proportions that the product had about 20 per cent that would pass through 200-mesh. The average of the screen tests of the coal dust used in the various tests was as follows:

<i>Average of screen tests of $\frac{1}{2}$-inch dust.</i>	
	Per cent.
Through $\frac{1}{2}$ inch.....	97.3
4-mesh.....	83.3
10-mesh.....	62.4
20-mesh.....	49.3
48-mesh.....	33.6
100-mesh.....	27.3
200-mesh.....	20.2

RESULTS OF THE TESTS.

Results of tests made with coal-dust distributions of 0.5, 1, 2, 4, and 6 pounds per foot are shown in Table 18.

TABLE 18.—Results of standard propagation tests of mixtures of $\frac{1}{4}$ -inch Pittsburgh coal dust, of which 20 per cent would pass 200 mesh, and pulverized pit-shale dust.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Ignition zone: Stations E 1300 to E 1250, pulverized Pittsburgh coal dust. Mixed dust zone: Stations E 1250 to E 950, 300 feet, and stations E 1250 to A 950, 350 feet; total length, 650 feet.]

Test No.	Date.	Ratio of coal dust to shale dust in mixture.	Rate of loading of coal dust in mixed dust.	Mixed dust.			Record obtained in entry or in air course.	Maximum pressure.		Time of tin-fol rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Propagation obtained.
				Rate of loading.	Total loading.	Per cent.		Station 1150.	Station 950.	Fol at station 1250.	Velocity.	Fol at station 1150.	Velocity.	Fol at station 1050.	Velocity.			Fol at station 950.
			<i>Lbs. per ft.</i>	<i>Lbs. per ft.</i>	<i>P or cent.</i>		<i>Lbs. per sq. in.</i>	<i>Lbs. per sq. in.</i>	<i>Secs.</i>	<i>Ft. per sec.</i>	<i>Secs.</i>	<i>Ft. per sec.</i>	<i>Secs.</i>	<i>Ft. per sec.</i>			
240	1915. Nov. 24	(e)	0.5	0.5	325	8.6	4	2	0.372	372	0.641	156	1.281	55	3.085	Fed. (b)	Yes.
246	Dec. 9	90:10	.5	.556	382	10.8	2	1	.418	206	.903	38	3.567	303	1.900	200 } 300	No.
249	Nov. 22	(e)	1.0	1.0	650	9.4	28	18	.457	427	.671	452	.892	900	1.037	(b)	Yes.
251	Nov. 30	80:20	1.0	1.25	812	26.3	11	7	.442	541	.627	366	1.028	763	1.215	(b)	Yes.
252	Dec. 1	70:30	1.0	1.43	980	35.9	3	2	.431	170	1.008	104	1.970	153	2.623	(b)	Yes.
250	Nov. 27	60:40	1.0	1.67	1,083	44.5	1	1	.381	43	2.666	.....	1.646	265	2.024	100 } 150	No.
254	Dec. 6	60:40	2.0	3.33	2,166	44.8	2	1	.421	201	.918	105	1.873	128	2.652	(b)	Yes.
253	Dec. 3	50:50	2.0	4.00	2,600	54.0	1	1	.420	47	2.540	174	1.618	516	1.812	100 } 175	No.
272	Nov. 17	c 50:50	2.0	4.00	2,600	53.5	1	2	.368	110	1.307	37	4.007	.....	.....	150 } 250	No.
255	Dec. 7	60:40	4.0	6.67	4,333	44.7	1	1	.245	98	1.324	35	4.176	.....	.....	150 } 200	No.
274	1916. Jan. 21	70:30	6.0	8.57	5,571	34.9	15	15	.370	249	.771	368	1.643	769	1.173	(b)	Yes.
320	May 6	60:40	6.0	10.00	6,500	44.7	4	5	.309	135	1.051	233	1.528	181	2.159	(b)	Yes.

a All coal.

b Flame extended through zone.

c 20-mesh shale dust use in this test.

DISCUSSION OF THE TESTS AND OF THE RESULTS.

The results of the first tests made (Nos. 248 to 256) seemed to show that the explosibility increased to a maximum with a coal-dust distribution of 2 pounds per foot and then dropped off, as indicated by test 255, in which propagation was not obtained with the use of 40 per cent shale dust, but this inference was later disproved.

The increase in explosibility with an increase in coal-dust loading from half a pound to 1 pound per foot is well illustrated by tests 249 and 248. Pure coal dust was used in both tests, this being distributed at the rate of half a pound per foot in test 249 and 1 pound per foot in test 248, respectively. Propagation was obtained in both tests, but in test 249 the maximum pressure at any station was 4 pounds per square inch and the maximum flame velocity was about 300 per second. In test 248, with the heavier loading, the pressure rose to 49 pounds per square inch at station A 950 and the maximum flame velocity was more than 1,400 feet per second. Also, in test 256, with a coal-dust loading of half a pound per foot, a mixture containing only 10 per cent shale dust sufficed to prevent propagation, whereas in test 250, with a coal-dust loading of 1 pound per foot, it was necessary to have 40 per cent shale dust in the mixture. Mixtures containing 20 per cent and 30 per cent shale dust loaded at the rate of 1 pound of coal dust per foot gave propagation in tests 251 and 252, respectively.

Increasing the coal-dust loading to 2 pounds per foot, propagation was obtained through a mixture of 60 per cent coal dust and 40 per cent shale dust in test 254. As before stated, a mixture of the same percentages had failed to propagate in test 250 when loaded at the rate of 1 pound of coal dust per foot. This indicates an increase in explosibility when the coal-dust loading is raised from 1 to 2 pounds per foot.

Propagation was not obtained in test 253 with a mixture of 50 per cent coal dust and 50 per cent "pulverized" shale dust, which shows that the increase in explosibility with an increase of coal-dust loading from one-half to 1 pound per foot is much greater than that which occurs when the coal-dust loading is increased from 1 to 2 pounds per foot.

In test 255 the mixture of 60 per cent coal dust and 40 per cent shale dust was again used, being loaded at the rate of 4 pounds of coal dust per foot of entry. Propagation was not obtained, the flame traveling a little more than half-way through the zones. This result would seem to indicate a decrease in explosibility. However, in test 320 the same percentages of coal dust and shale dust loaded at the rate of 6 pounds of coal dust per foot gave propagation, the pressures in this test being higher and the velocities similar to those

obtained in test 254, in which the mixture was loaded at the rate of 2 pounds of coal dust per foot of entry. Therefore it must be concluded that after 2 pounds of coal dust per foot of entry is reached other factors are more important than the quantity of coal dust present.

CONCLUSIONS AS TO EXPLOSIBILITY OF HALF-INCH DUST.

To summarize, the conclusion is that the explosibility increases rapidly with increase in the quantity of coal dust to 1 pound per foot, more slowly to 2 pounds per foot, and changes very slightly, if at all, beyond that point, there being no decrease which could be regularly detected in experimental mine testing. It can not therefore be argued that a large quantity of coal dust present will prevent an explosion or stop one that has started.

Test 272 was made with a mixture of 50 per cent coal dust and 50 per cent shale dust, the percentages being the same as in test 253, but the shale dust used in the former was 20-mesh size, whereas that used in the latter was 100-mesh dust. Thus, the shale dust used in test 253 would all pass through a 100-mesh screen and 97.1 per cent would pass through a 200-mesh screen, whereas of that used in test 272 only 40.7 per cent would pass through a 100-mesh and 29.6 per cent through a 200-mesh screen. This reduction in the number of fine shale particles was not sufficient, however, to permit propagation through the mixture in test 272.

It was noted that the coal-dust particles in tests 248 and 249 were considerably finer after the explosion than before. Some of the larger particles of coal, as might be expected, were broken in the explosion, becoming fine dust and assisting in the propagation. The explosibility curves described in subsequent pages indicate that this result is not of as great importance with the Pittsburgh coal dust as it may be for other softer or more friable coals.

Figure 31 shows the velocities of flame, as indicated by breaks in tin-foil circuits in tests 248, 249, 251, 252, 254, 274, and 320. The difference in velocities between tests 248 and 249, made with pure coal dust but with different rates of loading, is plainly shown. As would be expected, test 252 shows lower velocities than test 251, because the mixture used had a greater percentage of shale dust. The velocities in test 252 are also lower than those in test 274, in which the same mixture was used, but with a heavier loading. Tests 254 and 320, on the same mixture with different rates of loading, have about the same velocities, except that in the latter test the velocity within the entry was greater near the end of the zone. This fact might be explained by the fact that this part of the zone was usually wet. When the dust loading on the floor was deep, the top layer over a

wet spot would probably be drier than if the loading were shallow. The results of the tests with this dust are shown in Table 18.

The reader will note that both the flame velocities and the pressures were relatively low in this series as compared with those ob-

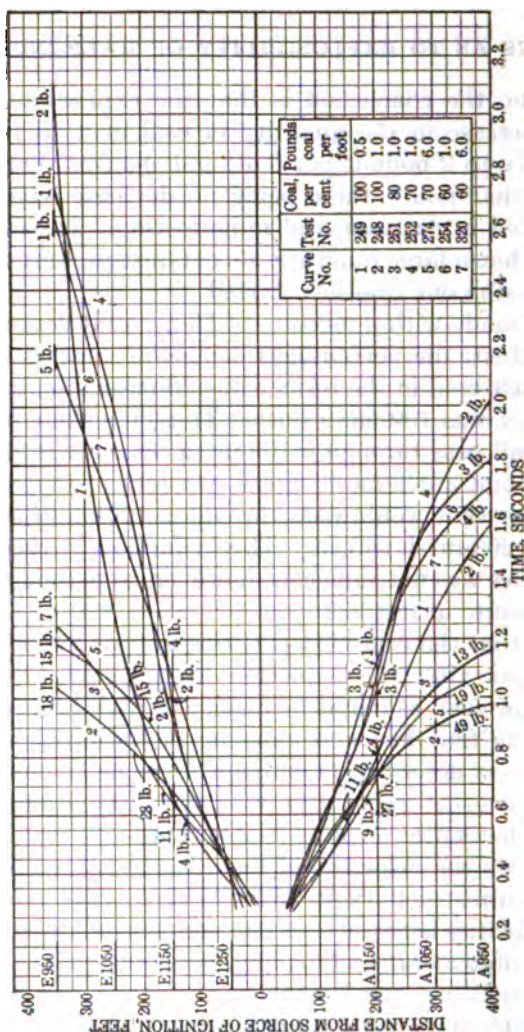


FIGURE 31.—Flame-velocity curves for propagation tests on mixtures of $\frac{1}{4}$ -inch Pittsburgh coal dust, 20 per cent of which would pass 200-mesh, and pit shale dust. Figures in *italic* denote number of curve, figures in roman denote maximum pressure developed at that point in pounds per square inch.

tained in tests of pulverized coal dust, even with higher percentages of rock dust in the mixtures, indicating the lesser explosibility of the coarser coal.

PROPAGATION TESTS WITH 20-MESH PITTSBURGH COAL DUST OF WHICH 40 PER CENT WOULD PASS THROUGH 200-MESH.**DESCRIPTION AND RESULTS.**

About 50 per cent of the $\frac{1}{4}$ -inch coal dust used in the series just described passed a 20-mesh sieve. Therefore a series of tests on the 20-mesh portion of the $\frac{1}{4}$ -inch dust was made for determining, by comparison with previous tests, the effect upon the explosive limits of leaving out particles of coal coarser than 20-mesh. Seventeen tests were made with 20-mesh Pittsburgh coal dust, 40 per cent of which would pass through a 200-mesh screen. The results are summarized in Table 19.

TABLE 19.—*Results of standard propagation tests of mixtures of 20-mesh Pittsburgh coal dust, 40 per cent of which would pass 200-mesh, and pit-shale dust.*
 [Originating cause: Standard blown-out shot from cannon at station E 1300. Ignition zone: Pulverised Pittsburgh coal dust stations E 1300 to E 1250. Mixed-dust zone: Stations E 1250 to E 940, 300 feet; stations E 1250 to A 960, 350 feet; total length, 650 feet.]

Test No.	Date.	Size of shale dust used.	Ratio of coal dust to shale dust in mixture.	Rate of loading of coal dust in mixed dust.	Mixed dust.			Record obtained in entry or in air course.	Maximum pressure.		Time of tin-foil ruptures at stations and flame velocity between stations.						Length of flame in mixed dust zone.	Propagation obtained.
					Rate of loading.	Total loading.	Calculated.		Gas used.	Station 1150.	Station 980.	Foil at station 1250.	Velocity.	Foil at station 1080.	Velocity.	Foil at station 980.		
275	Jan. 24, 1916.	Pulverised.	50:50	0.5	1.00	650	Pct. 53.5	Pct. 0.0	Lbs. per sq. in. 5	Lbs. per sq. in. 7	Sec. onds. 0.440	Ft. per sec. 238	Sec. onds. 0.390	Ft. per sec. 279	Sec. onds. 1.313	Ft. per sec. 299	Ft. 1.538	Yes.
257	Dec. 10, 1915.	do	50:50	1.0	2.00	1,300	54.0	0	8	12	.423	394	.677	216	1.129	380	1.402	Yes.
260	Dec. 17, 1915.	do	50:50	3.0	6.00	3,900	53.6	0	14	11	.477	418	.716	228	1.154	2,857	1.199	Yes.
261	Dec. 20, 1915.	do	50:50	5.0	10.00	6,500	53.4	0	12	10	.284	185	.826	306	1.183	704	1.265	Yes.
266	Mar. 8, 1916.	do	40:60	.5	1.25	812	62.7	0	3	3	.083	.....	.851	85	2.083	80	3.282	Yes.
258	Dec. 13, 1915.	do	40:60	1.0	2.50	1,625	62.8	0	3	3	.410	139	1.128	106	2.068	177	2.682	Yes.
259	Dec. 15, 1915.	do	40:60	2.0	5.00	3,250	62.8	0	2	1	.433	124	1.240	48	3.203	.....	175	No.
265	Dec. 20, 1915.	do	40:60	2.0	5.00	3,250	62.9	0	.....	2	.494	199	.926	136	1.660	362	2.042	Yes.
263	Dec. 22, 1915.	do	40:60	3.0	7.50	4,875	63.2	0	3	3	.433	121	1.260	72	2.654	1,887	2.717	Yes.
318	May 1, 1916.	do	40:60	4.0	10.00	6,500	63.2	0	2	2	.670	128	1.452	100	2.456	122	3.273	Yes.
266	Jan. 3, 1916.	do	30:70	1.0	2.33	2,166	73.1	0	2	2	.909	86	2.741	.....	.....	.....	100	No.
									.....	.....	.....	.....	.....	.....	.....	.....	175	No.

308	{ Apr. 5, 1916. }	.do....	30:70	2.0	6.67	4,333	72.0	.0	{ Entry.... Air course.	2	2	.492	43	2.817 1.507	.....	.....	.....	.....	100 } No. 175 }
270	{ Jan. 12, 1916. }	20-mesh	30:70	1.0	3.33	2,166	72.2	.0	{ Entry.... Air course.	3	2	.375	168	.969 1.143	68 103	2.435 2.111	207 346	2.917 2.400	(e) } Yes.
271	{ Jan. 14, 1916. }	.do....	25:75	1.0	4.00	2,600	77.0	.0	{ Entry.... Air course.	2	1	.273	38	2.908	.....	.....	.....	.....	75 } No. 100 }
444	{ Jan. 18, 1916. }	20-mesh	26:75	1.0	4.00	2,600	76.8	1.1	{ Entry.... Air course.	2	1	.385	127	1.174 1.080	44 136	3.450 1.814	137	2.600	175 } Yes. ^b (e) }
329	{ May 25, 1916. }	.do....	25:75	1.0	4.00	2,600	76.8	1.4	{ Entry.... Air course.	3	3	.275	220	.730 .853	81 197	1.962 1.360	76 233	3.283 1.701	(e) } Yes.
438	{ Dec. 26, 1917. }	.do....	20:80	1.0	5.00	3,250	81.3	2.0	{ Entry.... Air course.	2	1	.233	109	1.147 1.066	53 57	3.017 2.831	.....	.....	175 } No. 325 }

^a Flame extended through zones.^b In air course, but not in entry.

The dust was prepared by grinding in a hammer crusher equipped with a $\frac{1}{8}$ -inch slotted screen. About 96 per cent of the product obtained would pass through a 20-mesh screen; the small proportion of coarser dust was not screened out. Enough pulverized dust was mixed with the product from the crusher so that 40 per cent of the mixture would pass a 200-mesh sieve.

As previously mentioned (on p. 186), considerable difficulty was encountered in obtaining sieves which would give duplicate results on fine sizes. The screen used in tests of $\frac{1}{8}$ -inch dust permitted a larger proportion of the dust to pass through than did the one used in the later tests of this series; the actual percentage of fine sizes in the mixed dust was therefore greater in the latter tests (Nos. 268 and later).

The average of the screen tests of the coal dusts used in the various tests of the series is as follows:

Average screen analysis of coal dusts used.

	Per cent.
Through 20-mesh.....	96.6
Through 48-mesh.....	76.6
Through 100-mesh.....	58.5
Through 200-mesh ^a	40.0

Tests were made with distributions of 0.5, 1, 2, 3, 4, and 5 pounds of coal dust per foot of entry. The results obtained are plotted in figures 32 and 33, and are described in more detail in subsequent sections of this chapter. The results of the various tests are consistent with the exception of those for test 259. Several tests were made following this one before the inconsistency developed; then a duplicate of test 259, No. 265, was made and the opposite result obtained.

DISCUSSION OF RESULTS.

Propagation was obtained through a mixture of 40 per cent coal dust and 60 per cent shale dust, with the mixture distributed at the rates of 0.5, 1, 2, 3, and 4 pounds of coal dust per linear foot of entry, in tests 296, 258, 265, 263, and 318, respectively.

In tests 270, 271, 329, 438, and 444, 20-mesh shale, of which about 30 per cent would pass a 200-mesh screen, was used. In all other tests of this series the "pulverized" shale was used. In test 270 propagation was obtained through a mixture containing 30 per cent coal dust and 70 per cent shale dust, the 20-mesh shale dust being used, with a loading of 1 pound of coal dust per foot. Propagation had not been obtained in test 266, using pulverized shale dust in a mixture of the same percentages as test 270, and the same loading, nor in test 308 with a loading of 2 pounds per foot. In test 271 propa-

^a In tests 257 to 267 screen A was used, and in tests 268 to 444 screen B.

gation was not obtained through a mixture containing 25 per cent coal dust and 75 per cent 20-mesh shale dust. In these two tests the rate of loading was 1 pound of coal dust per foot.

Gas was used in three tests. A mixture containing 25 per cent coal dust and 75 per cent 20-mesh pit shale dust failed to give complete propagation in test 444 when there was 1.1 per cent of gas in the air current.* Propagation was obtained in the air course, but not in the entry. A similar mixture gave complete propagation in test 329 when there was 1.4 per cent gas in the air current. A mixture of 20 parts coal dust and 80 parts shale dust failed to give propagation in test 438, there being 2 per cent gas present. The flame, however, extended to within 25 feet of the end of the zone in the air course.

MAXIMUM SIZE OF COAL-DUST PARTICLES AFFECTING EXPLOSIONS.

In order to determine the effect of particles of Pittsburgh coal coarser than 20-mesh size (20-mesh screen openings are 0.0328 inch wide) on propagation, the percentages of shale dust in the various tests of the $\frac{1}{4}$ -inch coal-dust series were recalculated, leaving out of consideration those particles of coal dust coarser than 20 mesh. These new shale percentages were used in plotting a curve to show the amount necessary to prevent propagation for various amounts of loading. A second curve was drawn showing the results of the tests with 20-mesh coal dust, of which 40 per cent would pass through 200 mesh. These curves are presented in figure 32. The following table gives the figures from which the new shale percentages were calculated:

Data for recalculation of shale percentages.

Test No.	Percentage of $\frac{1}{4}$ -inch coal in mixture.	Percentage of $\frac{1}{4}$ -inch coal through 20 mesh.	Percentage of coal in mixture on 20-mesh basis.	Percentage of shale in $\frac{1}{4}$ -inch dust mixture.	Percentage of shale in mixture on 20-mesh basis.	Weight of coal dust per foot on 20-mesh basis (pounds).	Result.
249	100	45.8	100	0	0	0.23	(a)
256	90	49.8	81.7	10	18.3	.25	(b)
252	70	45.8	51.7	30	48.3	.46	(a)
250	60	45.8	46.7	40	59.3	.46	(b)
254	60	48.2	41.9	40	58.1	.96	(a)
253	50	47.1	32.0	50	68.0	.94	(b)
320	60	45.8	46.7	40	59.3	2.75	(a)

* Propagation.

† Did not propagate.

It will be noted that the curves in figure 32 correspond closely with those in figure 33 for 20-mesh coal dust. The conclusion is that, within the test distance, the presence of particles coarser than 20-mesh has no appreciable effect on the explosibility in limiting mixtures, that is to say, about the same amount of shale dust is required make a nonexplosive mixture.

The above conclusion with regard to the coarser particles corroborates the conclusion drawn from some tests in a 100-foot steel gallery, described in Bulletin 20,⁴ that Pittsburgh coal dust coarser than 20-mesh was relatively ineffective in an explosion. As a result of these conclusions, the general rule has been made of rejecting all particles coarser than 20-mesh in mine road-dust samples before analysis.

In the experiments subsequently made on mixtures of different sizes, having various percentages of 200-mesh dust present, dust coarser than 20-mesh size was not included in the mixtures to an appreciable amount.

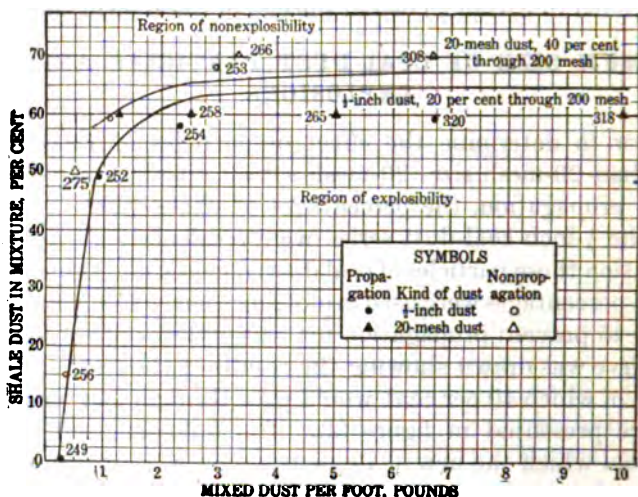


FIGURE 32.—Curves showing relative explosibility of 1-inch coal dust (of which 20 per cent will pass 200-mesh) recalculated to 20-mesh basis, and 20-mesh coal dust, of which 40 per cent will pass 200-mesh. Figures near symbols denote test numbers.

The coarser particles of a coal softer and more friable than the Pittsburgh coal may possibly be more effective than those of the Pittsburgh dust in assisting propagation. From study of an explosion disaster in a West Virginia mine working coal that is friable and has a columnar structure, where watering the roadway was practiced, the senior author concluded that, under these conditions, the air blast, which precedes the flame at a velocity exceeding a hurricane, might even abrade enough coal dust from the ribs of such mines to permit flame to propagate through wet zones. Such a result could be avoided by rock dusting the ribs so that the cloud of dust caused by the advance wave of an explosion would be nonexplosive.

The results of this series also indicate the value of fine grinding of the rock dust for lowering the explosibility limit. Comparison of

⁴ Rice, G. S., and others, The explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, p. 42.

tests 266 and 308 (Table 19), in which propagation was not obtained with a mixture having 70 per cent of pulverized shale dust, with tests 270 and 271, in which propagation was obtained with 70 per

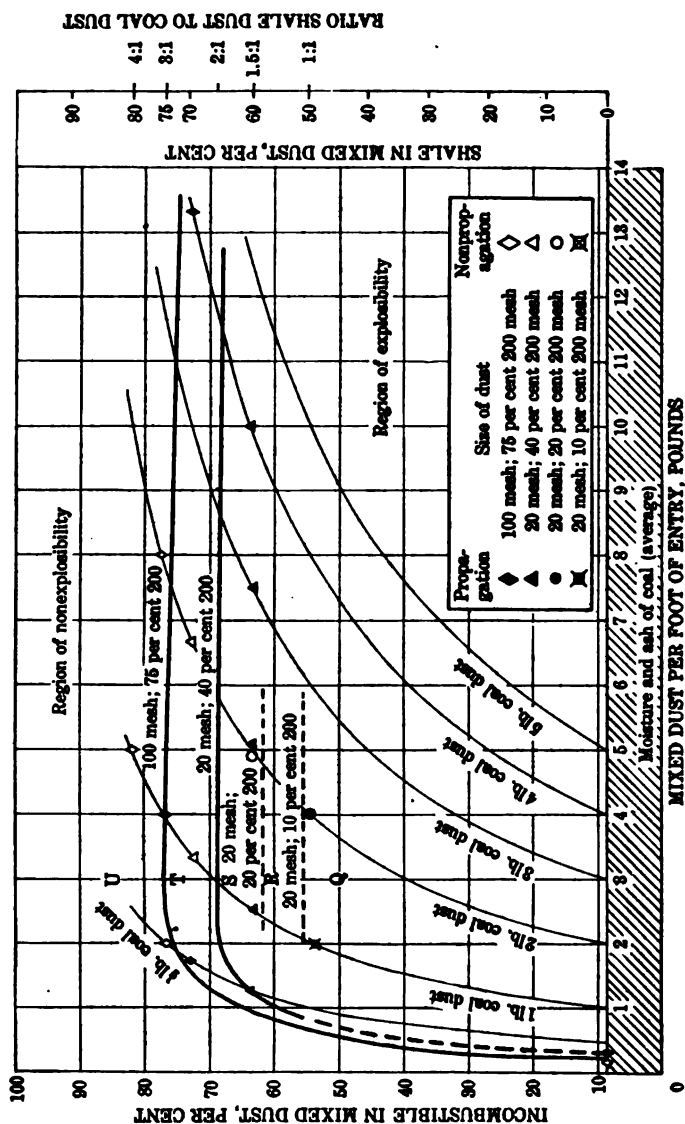


FIGURE 33.—Explosibility curves for Pittsburgh coal dust, showing effect of size and quantity of loading.

cent of 20-mesh shale dust, but was not obtained with 75 per cent of 20-mesh shale dust, indicates that pulverizing the shale lowers the explosibility limit about 5 per cent.

TABLE 20.—Results of standard tests of mixtures of 20-mesh Pittsburgh coal dust, of which 20 per cent would pass 200-mesh, and pit-shale dust.

[Originating cause: Standard blown-out shot from cannon at station E 1300.]

PROPAGATION TESTS.

Ignition zone, pulverised Pittsburgh coal dust, stations E 1300 to E 1350. Mixed-dust zone; Stations E 1350 to E 950, 300 feet; stations E 1350 to A 950, 350 feet; total length, 650 feet.

Test No.	Date.	Size of shale dust used.	Ratio of coal of shale dust in mixture.	Mixed dust.			Records obtained in entry or air course.	Maximum pressure.		Time of tin-fol rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
				Calculated combustible content.	Rate of loading.	Total loading.		Station 1150.	Station 950.	Fol at station 1250.	Ve-locity.	Fol at station 1150.	Ve-locity.	Fol at station 1050.	Ve-locity.	Fol at station 950.	
				Per cent.	Lbs. per ft.	Lbs.	Per cent.	Lbs. sq. ft.	Lbs. sq. ft.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	
277	{ Jan. 25, 1916.	Pulver- ised.	{ 50-50	54.3	4.0	2,600	0.0	3	2	0.429	196	0.940	130	1.710	230	2.165	{ Propagation ob- tained.
317	{ Apr. 25, 1916.	.do....	{ 40-60	63.8	5.0	3,220	.0	3	2	.428	44	2.698	.....	.....	.....	.....	{ Propagation not obtained.
439	{ Dec. 2, 1917.	30-mesh	{ 40-60	63.0	2.50	1,625	.9	8	8	.265	162	.884	275	1.248	328	1.553	{ Propagation ob- tained.
443	{ Jan. 16, 1918.	.do....	{ 30-70	72.5	3.33	2,167	1.2	1	1	.189	43	2.460	.....	.....	.....	.....	{ Propagation not obtained.
437	{ Dec. 21, 1917.	.do....	{ 25-75	77.0	4.00	2,600	1.9	2	2	.421	232	.833	61	2.468	.....	.....	{ Propagation ob- tained in air course, but not in entry.

IGNITION TESTS.
Mixed-dust zone; Stations E 1300 to E 940, 350 feet; stations E 1250 to A 940, 350 feet; total length, 700 feet.

244	Nov. 10, 1916.	30-mesh	70:30	35.0	2.86	2,000	.0	{Entry..... {Air course.	19 17	18 20	0.710	188	1,243 1,302	330 1,206	1,546 1,331	1,089 896	1,437 1,505	{(e) 125 175	Ignition obtained. Ignition not ob- tained.
328	May 24, 1916.	do	60:40	45.0	3.33	2,333	.0	{Entry..... {Air course.	1	1	1.273	39	3,838						
349	Nov. 22, 1916.	do	60:40	44.7	3.33	2,333	.0	{Entry..... {Air course.	6 4	7 4	.912	71	2,313 1,576	638	2,465	331	2,180	{(e) 75 100	Ignition obtained. Ignition not ob- tained.
316	Apr. 27, 1916.	do	50:50	53.5	4.00	2,800	.0	{Entry..... {Air course.	1 1	1 1	.906								
440	Jan. 3, 1918.	do	40:60	62.7	2.50	1,875	2.1	{Entry..... {Air course.	1 1	1 1			2,814					100 200	Do.

* Flame extended through zone.

TESTS WITH 20-MESH PITTSBURGH COAL DUST OF WHICH 20 PER CENT WOULD PASS THROUGH 200-MESH.

Ten tests were made in this series, five propagation tests and five ignition tests. The average of the screen tests of the coal dusts used is as follows:

<i>Average screen analysis of coal dusts used.</i>		Per cent.
Through 20-mesh.....		95.7
Through 48-mesh.....		64.8
Through 100-mesh.....		36.5
Through 200-mesh:		
Screen A.....		24.4
Screen C.....		20.2
Screen B.....		19.8

The results of the tests with 20-mesh dust, of which 20 per cent would pass a 200-mesh screen, are given in Table 20.

PROPAGATION TESTS.

In test 277 a mixture containing 50 per cent coal dust and 50 per cent pulverized pit shale dust, distributed at a rate of 4 pounds per foot, gave a weak explosion. In test 317 the percentage of pulverized shale dust was increased to 60 per cent and with this mixture propagation was not obtained. No gas was used in either of these tests.

In test 439 propagation was obtained through a mixture of 40 parts coal dust and 60 parts 20-mesh shale dust, with 0.9 per cent gas in the air current. In test 443 propagation was not obtained through a mixture of 30 parts coal dust and 70 parts 20-mesh shale dust, there being 1.2 per cent gas in the air current. In test 437 complete propagation was not obtained through a mixture containing 25 per cent coal dust and 75 per cent 20-mesh shale dust, there being 1.9 per cent gas in the air current. The flame reached the end of the zone in the air course, but stopped 75 feet short in the entry. Complete propagation might be obtained with 2 per cent of gas present.

Inasmuch as many samples of road dust from commercial mines have about this percentage of fine sizes, it is important to note that propagation can not be obtained through a 60 per cent shale-dust mixture, although propagation can be obtained under favorable conditions through a 75 per cent shale-dust mixture when pulverized coal and shale dusts are used, there being no gas in the ventilating current in either case.

IGNITION TESTS.

In addition to the propagation tests on this size of dust five ignition tests (Nos. 316, 328, 344, 349, and 440) were made in order to get a basis for comparing them with ignition tests of coals from other mines.

In test 316 the mixture used contained 50 per cent 20-mesh pit-shale dust and 50 per cent 20-mesh Pittsburgh coal dust, of which 20 per cent passed through a 200-mesh sieve. Ignition was not obtained. Flame traveled only to the 1,225-foot point on the entry, or 75 feet from the cannon (as indicated by bromide paper), and to the air course end of the 1,250 cut-through, 100 feet from the cannon. In test 328 the same sizes of shale dust and coal dust were used, with a mixture of 60 per cent coal dust and 40 per cent shale dust. Ignition was not obtained in this test either, the flame traveling to stations E 1175 and A 1175 only, 125 feet and 175 feet from the cannon, respectively. The mine was quite wet in places when this test was made, and the moisture may have had a quenching effect on the initial explosion.

In test 344 a mixture containing 70 per cent coal dust and 30 per cent 20-mesh pit-shale dust was distributed at the rate of 2.86 pounds of mixed dust per foot of entry. A very strong ignition was obtained, pressures of 18 and 26 pounds being recorded at stations E 950 and A 950, respectively.

As a result of the high pressures obtained in this test it was decided to repeat the earlier test (No. 328) with 60 per cent coal-dust and 40 per cent shale-dust mixture while the mine was dry. This was done in test 349 and ignition was obtained.

One ignition test (No. 440) was made with 2.1 per cent of gas in the air current. A mixture containing 40 per cent coal and 60 per cent 20-mesh shale was used; no ignition was obtained.

**TESTS WITH 20-MESH PITTSBURGH COAL DUST, OF WHICH
10 PER CENT WOULD PASS THROUGH A 200-MESH SCREEN.**

Twelve propagation and ignition tests were made in this series, the results of which are shown in Table 21. The average of the screen tests of the coal dusts used is as follows:

Average screen analysis of coal dusts used.

	Per cent.
Through 20-mesh.....	93.4
Through 48-mesh.....	55.5
Through 100-mesh.....	25.4
Through 200-mesh:	
Screen A.....	11.7
Screen C.....	10.0
Screen B.....	9.2

TABLE 21.—Results of standard tests of mixtures of 20-mesh Pittsburgh coal dust, of which 10 per cent would pass through a 200-mesh screen, and pit-shale dust.

[Originating cause: Standard blown-out shot from cannon at station E 1300.]

PROPAGATION TESTS.

Ignition zone, pulverized Pittsburgh coal dust, stations E 1200 to E 1250. Mixed-dust zone: Stations E 1250 to E 950, 300 feet; stations E 1250 to A 950, 350 feet; total length, 650 feet.

Test No.	Date.	Size of shale dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-fall rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
				Calculated content.	Rate of loading.	Total loading.		Station 1150.	Station 950.	Pit at station 1250.	Ve. locality.	Fall at station 1150.	Ve. locality.	Fall at station 1050.	Ve. locality.	Fall at station 950.	
332	Nov. 28, 1916	20-mesh	60:40	Per cent. 44.0	Lbs. per ft. 3.33	Lbs. 2,167	Per cent. 0.0	Lbs. per sq. ft. 5	Lbs. per sq. ft. 6	Sec. on fall 0.418	Ft. per sec. 176	Sec. on fall 0.985	Ft. per sec. 157	Sec. on fall 1.046	Ft. per sec. 254	Sec. on fall 2.039	Propagated. (e)
325	May 16, 1916	Pulverized.	50:50	53.4	4.0	2,600	0	1	1	.500	45	2.725	.....	.....	.....	.....	Propagated. Not obtained. Mine wet.
326	May 17, 1916	...do....	50:50	53.4	4.0	2,600	0	1	1	.568	121	1.417	29	4.916	.....	.....	Do.
372	Jan. 18, 1917	...do....	50:50	53.7	2.0	1,300	0	1	1	.308	148	.955	61	2.418	67	4.118	Propagated. (e)
435	Dec. 14, 1917	20-mesh	40:60	62.9	2.50	1,625	1.1	1	1	.304	120	1.140	.....	.....	.....	.....	Propagated. Not obtained.
484	Dec. 11, 1917	...do....	80:70	72.9	3.33	2,167	1.8	3	3	.245	181	.798	.....	.....	105	2.710	Propagated. (e)

IGNITION TESTS.

Mixed-dust zone: Stations E 1890 to E 950, 350 feet; stations E 1890 to A 950, 350 feet; total length, 700 feet.

353	Dec. 1, 1916	20-mesh	80:20	25.6	2.50	1,750	0.0	Entry..... {Air course.	1	1	0.776	37	3.514	2.350	.....	.....	.....	200 150	Ignition not ob- tained. No dust placed on floor.
355	Dec. 16, 1916	do.	80:20	25.6	2.50	1,750	.0	Entry..... {Air course.	4 3	5 3	.973	67	2.461	1.729	360 180	2.739 2.285	281 260	3.095 2.659	Ignition ob- tained.
351	Nov. 27, 1916	do.	70:30	24.6	2.86	2,000	.0	Entry..... {Air course.	1 1	1 1	.875	63	2.463	1.968	51 90	4.413 3.099	.....	275 250	Ignition not ob- tained.
442	Jan. 11, 1918	do.	80:40	45.1	1.87	1,250	1.3	Entry..... {Air course.	1 1	1 1	3.943	.....	.....	.....	.....	.....	.....	75 150	Do.
441	Jan. 9, 1918	do.	80:40	46.9	1.67	1,250	1.9	Entry..... {Air course.	7 7	9 8	.702	94	1.767	1.701	174 316	2.342 2.017	935 429	2.449 2.250	Ignition obtained.
436	Dec. 18, 1917	do.	50:50	54.0	2.00	1,500	2.0	Entry..... {Air course.	1 1	1 1	1.067	28	4.628	.....	.....	.....	.....	100 200	Ignition not ob- tained.

* Flame extended through both zones.

PROPAGATION TESTS.

In test 352 a strong propagation was obtained with a mixture containing 60 per cent coal dust and 40 per cent 20-mesh shale dust, loaded at the rate of 3.33 pounds of mixed dust per foot.

In test 325 a mixture containing 50 per cent coal dust and 50 per cent pulverized shale dust was used at the rate of 4 pounds of mixed dust per foot. In test 326 the mixture had the same percentage of constituents, but 20-mesh shale dust, of which only 25.7 per cent passed through 200-mesh, was used. Propagation was not obtained in either of these tests.

In the light of later tests with other coal dusts the results of these tests seemed to be inconsistent. As they had been made when the mine was very wet, it was decided to repeat the test of the mixture of 50 per cent coal dust and 50 per cent 20-mesh shale dust with the mine surfaces free from moisture. This was done in test 372; the explosion obtained was weak.

Two propagation tests were made with gas in the ventilating current. In test 435 propagation was not obtained through a mixture of 40 parts coal dust and 60 parts 20-mesh shale dust, with 1.1 per cent gas in the air current. Propagation was obtained in test 434 through a mixture of 30 parts coal dust and 70 parts 20-mesh shale dust, there being 1.8 per cent gas in the air current.

The result of test 435 does not seem to be consistent with the results obtained in tests 372 and 434. It is possible that a repetition of test 435 might give different results.

In comparing the results with the group of five propagation tests in Table 20—Pittsburgh coal dust with twice as much (20 per cent) passing through a 200-mesh sieve—it is seen that in one test (277) propagation was obtained with 60 per cent shale dust in the mixture. As to the last group—only 10 per cent of the dust of which passed through a 200-mesh sieve—in only one test out of three was propagation obtained with a mixture containing ten per cent less shale dust. This result indicates at least a 10 per cent lower propagation limit for the dust with 10 per cent less of pulverized size in the mixture.

IGNITION TESTS.

Six ignition tests were also made with this size of coal dust in order to obtain comparison with the dusts from other mines.

A mixture of 80 per cent coal dust and 20 per cent 20-mesh shale dust failed to give ignition, loaded at the rate of 2.5 pounds of mixed dust per foot. Through a misunderstanding the dust was not properly distributed in this test, no dust being placed on the floor; therefore this mixture was tried again in test 355 with part of the loading placed on the floor, and ignition was obtained.

In test 351 ignition was not obtained with a mixture containing 70 per cent coal dust and 30 per cent 20-mesh shale dust distributed at the rate of 2.86 pounds of mixed dust per foot.

In test 442 ignition was not obtained through a mixture containing 60 per cent coal dust and 40 per cent 20-mesh pit-shale dust, with 1.3 per cent gas in the air current, but was obtained in test 441 through a similar mixture, there being 1.9 per cent gas in the air current. Ignition was not obtained in test 436 through a mixture of 50 per cent coal dust and 50 per cent 20-mesh shale dust, with 2.0 per cent gas in the air current.

Although the majority of the road-dust samples collected in mines of various districts contained less than 10 per cent of dust which would pass through a 200-mesh screen, in almost every mine it is possible in some places to find road dusts with larger proportions of the finest dust. Moreover, rib and timber dust is likely to be fine; therefore it was not considered wise in preparing samples for explosibility testing to use less than 10 per cent of 200-mesh dust in the 20-mesh dust.

SUMMARY OF TESTS SHOWING INFLUENCE OF SIZE AND QUANTITY OF DUST.

The limiting tests of all mixtures of dust finer than 20-mesh for different weights of coal dust distributed are shown in Table 22.

For each size of dust and each weight of coal dust distributed the mixture of coal dust and shale dust that will permit propagation and that which will not are given so far as the information is available. For each mixture of coal dust and shale dust the corresponding percentage of incombustible present is also given.

TABLE 22.—Data on limiting mixtures of various sizes of Pittsburgh coal dust and shale dust.

Coal dust used per foot of entry.	Propagation or nonpropagation.	100-mesh dust (75 per cent through 200-mesh).		20-mesh dust (40 per cent through 200-mesh).		20-mesh dust (20 per cent through 200-mesh).		20-mesh dust (10 per cent through 200-mesh).	
		Shale.	Incombustible.	Shale.	Incombustible.	Shale.	Incombustible.	Shale.	Incombustible.
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Pound.	Propagation.....								
0.15.....	Nonpropagation.....	0	5.4						
.3.....	Propagation.....	0	8.2						
	Nonpropagation.....								
.5.....	Propagation.....	70	71.8	60	62.7				
	Nonpropagation.....	75	76.5						
1.....	Propagation.....	75	76.6	60	62.8			50	53.7
	Nonpropagation.....	80	81.4	70	73.1				
2.....	Propagation.....			60	62.8	50	54.2		
	Nonpropagation.....	75	76.8	70	72.1	60	63.8		
3.....	Propagation.....			60	63.2				
	Nonpropagation.....								
4.....	Propagation.....	70	71.8	60	63.2				
	Nonpropagation.....								

The results of the tests shown in this table are plotted in figure 33 (p. 205). These curves show the percentage of incombustible necessary to prevent propagation through various sizes and amounts of Pittsburgh coal dust when no gas is present. The figures along the bottom of the chart represent pounds of mixed dust per linear foot of entry. (The average cross section of the test zone in the experimental-mine entries is 58.2 square feet.) The figures on the left side show the percentage of incombustible, which consists of the shale dust plus the moisture and ash of the coal dust, in the mixture used.

The shaded portion across the bottom of the curves represents the average moisture and ash content (8.9 per cent) of the Pittsburgh coal used in these tests.

The first scale on the right shows the percentage of shale in the mixed dust. The scale farthest to the right shows the ratio of shale dust to coal dust. From these two scales a mixture having 75 per cent of shale dust is seen to contain shale and coal in a ratio of 3 to 1. Moving horizontally across the diagram to the left side this mixture is seen to contain 77.2 per cent incombustible (an average value).

The light curved lines marked "1 lb., 2 lb., 3 lb., of coal dust," etc., show the amount of coal dust present in any total mixture; that is, a loading of 9 pounds of mixed dust, having 50 per cent incombustible, is seen to contain 5 pounds of coal dust.

The heavy curve marked "100-mesh 75 per cent 200" defines the limiting mixture of propagation for different loadings of so-called "pulverized Pittsburgh coal." In these tests the rate (density) of loading was varied from 0.15 pound of pure coal dust per foot of entry (0.041 ounce per cubic foot of air space) to 13.3 pounds of mixed dust per foot. It is seen that practically the same percentage of incombustible is necessary to prevent propagation for all quantities of dust containing 1 or more pounds of coal dust per foot of entry (0.275 ounce per cubic foot). Propagation was obtained with 0.3 pound of pure coal dust per foot of entry (0.082 ounce per cubic foot of air space), but was not obtained when the loading was reduced to 0.15 pound per foot of entry.

The tests have indicated that coal particles larger than 20-mesh have no perceptible effects within the limits of testing. As already stated, only coal particles passing through a 20-mesh screen were used for standard testing and this was further screened to determine the proportions passing through a 200-mesh screen, the standard proportions for testing being 10, 20, 40, and 75 per cent, respectively.

The second heavy curve shows the explosibility of 20-mesh coal dust, 40 per cent of which will pass through a 200-mesh screen. It is seen that 70 per cent incombustible in a mixture of this size of coal dust prevents propagation under test conditions, regardless of the amount of dust present.

The explosibility of 20-mesh coal dust, of which 20 per cent will pass through 200-mesh and that of 20-mesh coal dust of which 10 per cent will pass through 200-mesh is shown by the broken-line curves. Mine samples gathered in different coal fields have, in many instances, shown (even for the dusts gathered from the ribs and timbers) a less proportion passing through 200-mesh; hence have a lower explosive limit than the dusts tested. The following examples show the method of interpreting the curves: A point below any curve is understood to represent a condition that will propagate an explosion, whereas a point above a curve represents a condition of nonexplosibility with reference to that curve. Take five points on the chart shown by the letters Q, R, S, T, and U, all representing a loading of 3 pounds of mixed dust per foot. A mixture, represented by Q, containing 50 per cent incombustible would propagate an explosion if 10 per cent of the coal dust passes through 200-mesh, because the point Q falls below the 10 per cent curve. A condition represented by the point R, showing 60 per cent incombustible, would not propagate if only 10 per cent of the coal dust passes through 200-mesh, but would propagate if 20 per cent of the coal dust is 200-mesh or finer, because the point R lies between these two curves.

Likewise a condition represented by the point S would not propagate with a mixture containing 20 per cent of 200-mesh coal dust, but would propagate with one containing 40 per cent of 200-mesh coal dust.

At the point T propagation would not be obtained with 40 per cent of 200-mesh coal dust, but would be obtained with 75 per cent of 200-mesh coal dust, whereas, as shown by U, 80 per cent incombustible would prevent propagation through the fine "pulverized" coal dust under test conditions. This size of dust is rarely found in quantity in mines except the float dust on timbers and clinging to the roof and walls like soot. The curves relate to propagation when no fire damp is present, as previously stated; for each per cent of methane present less than the explosive minimum ($5\frac{1}{2}$ per cent), from 5 to 10 per cent additional shale dust is required to offset it.

These tests were made with dust prepared from Pittsburgh coal mined from the experimental mine. The relation of the limiting curves of explosibility of the various sizes of coal dust is likely to vary from that of dust from other coal beds.

INFLUENCE OF QUANTITY.

It will be noted in figure 33 that only with the pulverized dust (100-mesh dust, 75 per cent of which would pass through 200-mesh) was propagation obtained with any one loading of coal dust where propagation could not be obtained through the same coal-dust and

shale-dust mixture with a different distribution. The instance referred to is the one in which propagation was obtained through a mixture of 75 per cent pulverized shale dust and 25 per cent coal dust, distributed at the rate of 1 pound of coal dust per foot, but was not obtained through the same mixture with different weights of dust distributed. Too much weight should not be attached to the one test in which an explosion resulted, because propagation was not obtained through the same mixture with nearly the same weight of coal dust distributed ($1\frac{1}{2}$ pounds per foot) in several tests with pulverized dust. Also in test 300, with one-half pound of dust distributed, propagation was almost obtained. Therefore the

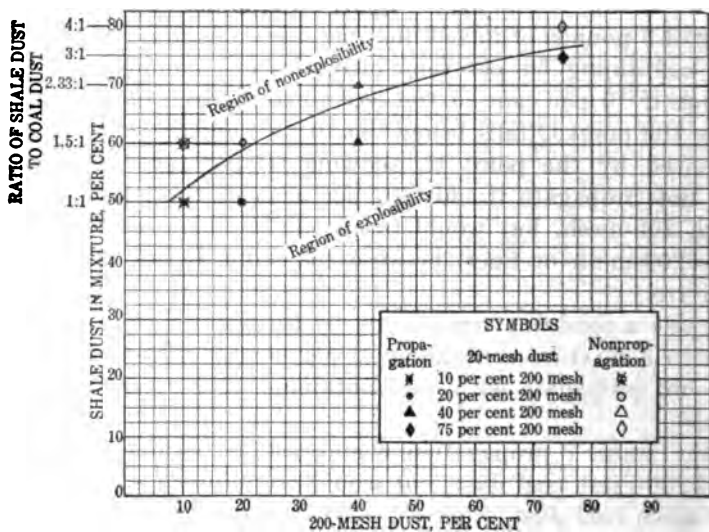


FIGURE 34.—Curve showing effects of size of coal dust on explosibility.

liability of obtaining an explosion through mixtures of 75 per cent shale dust and 25 per cent coal dust is probably nearly the same with dust distributions corresponding to rates of one-half to 2 pounds of coal dust per foot.

In the 20-mesh dust, 40 per cent of which passes through 200-mesh, the limits were the same for all the weights of coal dust tested.

The curves shown in figure 33 therefore are practically horizontal, indicating about the same explosibility for the same mixtures of shale dust and coal dust irrespective of the amount distributed. For this reason it was thought to be unnecessary to run tests with the other sizes of coal dust with more than one weight of coal dust per foot of entry.

EFFECT OF FINE DUST.

The effect of the percentage of fine coal dust on the explosibility of a mixture is shown by the curve in figure 34. The percentage of coal dust that will pass through 200-mesh is shown along the bottom of the diagram. Along the left-hand side are shown the corresponding percentages of shale dust in the different mixtures of coal dust necessary to prevent propagation of an explosion. The points with solid centers represent tests in which propagation was obtained; the hollow points represent tests in which propagation was not obtained.

This curve brings out strikingly the increased explosibility with the increased fineness of the dust. It will be noted that for an increase from 10 per cent to 75 per cent of 200-mesh dust the percentage of shale dust necessary to prevent propagation increases from 55 to 80, or, in other words, the ratio of the quantity of shale dust to coal dust increases from about 1:1 to 4:1. The percentage of fine dust present in mine-dust samples is therefore a factor of great importance in determining the liability of an explosion propagating. Following the tests of this series, the practice of making screen tests on all road-dust samples from commercial mines was adopted, so as to get more accurate information on the explosibility of the dust.

It is highly probable, however, that the effect of size of dust differs for different coals. The Pittsburgh coal used in these tests is comparatively hard, and consequently in an explosion is not as likely to yield a large percentage of fine dust from breakage of the larger particles as are some coals that are softer and more friable.

Therefore when the results of these tests with Pittsburgh coal are used to predict the comparative explosibility of various sizes of some other coal, due allowance must be made for greater friability if the coal crumbles easily.

CHAPTER VI.—TESTS WITH THE DUSTS OF COALS OTHER THAN PITTSBURGH.

METHODS OF SAMPLING.

From time to time and after the period when the methods of testing were being standardized, as described in the preceding pages, large samples of coal were obtained from different coal beds in order to determine the relative explosibility of the dusts in air. A number of the mines from which these samples were obtained had previously experienced violent coal-dust explosions, wrecking the mines and killing hundreds of men. These samples were obtained through the courtesy of the operators and mainly at their own expense. Each comprised 3 to 5 tons of run-of-mine coal. Where the distance from the experimental mine was great, the samples were cut down to about 3 tons in order to reduce the transportation charges. While the larger samples permitted more tests, 3 tons were usually enough to obtain general limits. Freshly mined coal was always obtained and was placed in tight boxes or barrels immediately after mining to prevent loss of moisture and volatile matter, the packing preferably being done at the face of the mine.

Besides obtaining the sample of run-of-mine coal which, so far as possible, represented the average of the coal bed, the rib and timber dusts were systematically sampled from the face to the shaft in order to obtain information regarding (1) the purity of the dust; (2) the character of the admixed inert dust; (3) the percentage of moisture; (4) the sizes of the natural dust passing through a 20-mesh screen, which was taken as the maximum size of dust entering into the initiation of the explosion, as explained elsewhere. Hence only that part of the samples thus gathered which passed through a 20-mesh sieve was considered, and sizing tests were made to determine the different percentages of each size and as far as possible the composition of each size of the dust. In addition samples of the floor and roof, where these entered into the road-dust mixtures, were gathered for study. Mine air samples were collected because the presence of small quantities of fire damp affects the explosibility limits. The standard method of sampling the mine dust for the purpose is given on page 490.

The unavoidable production of coal dust in the mine is discussed in Chapter VIII (p 383).

EXPLOSION HAZARD OF A SPECIFIC MINE.

In addition to the information to be gained by testing coal dust from different coal beds, there was another objective in taking the samples in the manner indicated. The bureau was enabled thus to make a specific report to the operator as to the degree of danger of an explosion originating in any particular part of his mine, and what could be done immediately to remedy and reduce that risk to a basis of practically no hazard. Such recommendations usually called for: (1) Removal of coal dust accumulations; (2) spreading of specific amounts of limestone or shale dust, or as an alternative, thorough continued watering; (3) in gaseous mines, reduction—by specific changes in ventilation—of methane content of particular air currents; (4) as an additional precaution, the installation of rock dust barriers, such as described in Chapter IX, for the limitation of an explosion that might start through local failure of precautions, the barriers being placed near junction points and at the entrances of panels.

In addition to the above recommendations relating to making coal dust less dangerous, other recommendations would often be found necessary by the examining engineer regarding lessening production of coal dust at the face or on roadways; and prevention of means of igniting coal dust, such as (1) use of permissible explosives in place of black powder or dynamite; (2) use of permissible electric lamps by miners; (3) specified precautions in the installation and use of electric power and transportation lines underground; (4) possible improvements in mine ventilation. Each report thus made has generally been received favorably by the respective mine management and the recommendations accepted as a whole or in part.

METHODS OF EXPLOSION TESTING.

The dusts of these coals from different mines were tested under the standard ignition and propagation conditions, as described in the preceding pages, in the cement-lined passages of the mine, for the purpose of determining the relative explosibility of the pure coal dust on the basis of the amount of inert matter which must be added to prevent ignition and propagation.

In ignition tests the mixture of coal dust and shale dust was distributed from the face of the entry outby for a distance of 350 feet in the main entry. Beginning at a point 50 feet from the face, the mixture was also distributed for a distance of 50 feet through the last cut-through, thence 300 feet outby along the parallel entry, termed the air course. A standard blown-out shot of 4 pounds of FFF black blasting powder was fired into the mixture from a cannon at the face of the main entry

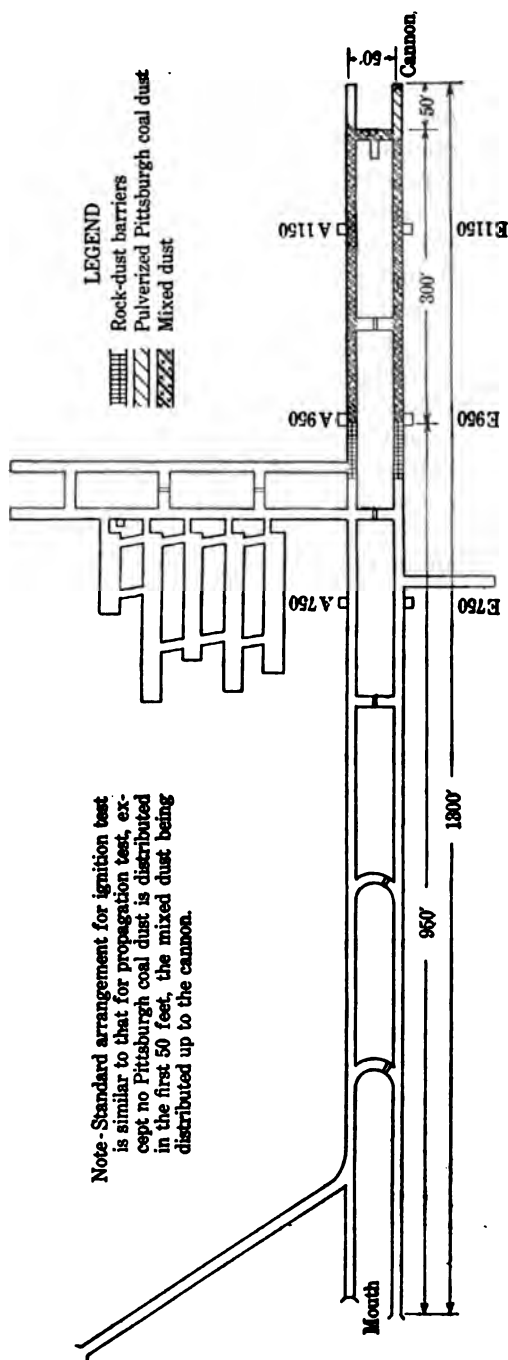


FIGURE 35.—Diagram showing arrangement of zones in a standard propagation test.

In propagation tests the loading was the same as for ignition tests except for the first 50 feet out by the cannon at the face of the entry; that is, from the face to the cut-through. "Pulverized" or 100-mesh Pittsburgh coal dust free from admixture of shale was distributed in this 50-foot zone and ignited by firing the standard blown-out shot into it. As stated previously, the explosion of this zone of Pittsburgh dust gives approximately the same effect as an explosion of a 50-foot body of explosive gas, or an effect similar to that obtained by an explosion in a longer zone of the pure dust under test if of less explosibility than the standard Pittsburgh dust. The arrangement of zones in a propagation test is shown in figure 35.

Although some objections might be raised to using this starting zone of Pittsburgh dust when testing a different kind of coal, it was decided that there is a possi-

bility of an explosion of gas in almost any coal mine which would give an effect equivalent to the 50-foot Pittsburgh dust explosion, as described on page 162. It has been determined by test that the dust and flame from this 50-foot zone is not carried more than 50 feet beyond the ignition zone and at a low pressure. The result is therefore, in effect, nothing more than a method of starting explosions, which does not affect the determination of the liability of the particular coal being tested to propagate an explosion, the special object being to get a uniformly violent source of ignition, in order to get an exact comparison of dusts of the different coals. The 50-foot ignition zone of pulverized Pittsburgh coal dust was therefore adopted for standard "propagation" tests with all coals, the "ignition" test showing if the dust under test will ignite with a lesser means, namely, a blown-out shot of 4 pounds of black powder.

At the time when the first of these samples were received no testing had been done with the coarse sizes of Pittsburgh coal dust. Therefore, in order to have a standard basis of comparison, the tests were made with pulverized dusts; that is, practically all of the dust would pass through 100-mesh and 70 to 80 per cent through 200-mesh, depending upon the hardness of the coal. Later, when the method of testing had been developed, a coal was tested first with 20-mesh dust containing approximately the same percentage of 200-mesh dust as the road-dust samples taken in the same mine from which the coal was obtained. These tests were made either without gas, with 1 per cent, or with 2 per cent, depending upon the percentage of gas found in the air samples taken from the same mine. The coal remaining after testing the coarse dust was then pulverized and further tests made with the fine dust for comparative purposes.

It had been determined in the course of the earlier testing that the relative explosibility of various coal dusts when dry depends largely upon the percentage of volatile matter. For this reason different coals are rated by the ratio of "volatile combustible" to "total combustible," or, in other words, the percentage of volatile matter present after the moisture and ash have been excluded. Accordingly in getting samples for the earlier testing an effort was made to obtain coals representing as wide a range of volatile content as possible.

THE COALS TESTED.

The coal dusts that have been tested up to the time of preparation of this bulletin are given in the following list and are typical of the coals mined in the various districts. In this list the coals are arranged in the order of their ratios of volatile to total combustible, beginning with the highest ratio. The specific ratios of these coals are given on page 344.

Coal dusts tested.

Source.

No. 5 bed.....	Indiana.
Vancouver Island coal.....	British Columbia.
No. 4 bed.....	Montana.
No. 6 bed (Southern district).....	Illinois.
Trinidad coking coal.....	Colorado.
Owl Creek bed.....	Wyoming.
Pittsburgh bed.....	Experimental mine, Pa.
Keokee bed.....	Eastern Kentucky.
Upper Freeport, or E, bed.....	Indiana County, Pa.
Sewell bed.....	West Virginia.
Coking coal bed (Crow's Nest field).....	British Columbia.
Lower Kittanning, B, or Miller bed.....	Clearfield County, Pa.
Fire Creek bed.....	West Virginia.
Upper Freeport, or E, bed.....	Cambria County, Pa.
Beckley bed.....	West Virginia.
Lower Kittanning bed.....	Cambria County, Pa.
Anthracite.....	Bernice field, Pa.
Anthracite.....	Lykens Valley, Pa.
Anthracite (two samples).....	Wyoming Valley, Pa.

EXPLOSIBILITY TESTS OF COAL DUST FROM NO. 5 SEAM, INDIANA.

GENERAL CHARACTER OF EXPLOSION TESTS.

A series of eight explosion tests was made with coarse and pulverized dusts prepared from a 5-ton sample of coal from a mine in Indiana working the No. 5 bed. The object of this series was to determine the percentages of shale necessary to prevent ignition and to prevent propagation of an explosion under standard test conditions, both with and without gas in the ventilating current. One set of tests was made with dust crushed to the standard size nearest to the size of dust found in the mine from which the coal was taken. A second set was made with pulverized dust in order to obtain the maximum explosibility of the coal for comparison with coals from other seams.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Examination was made of the conditions in the mine from which this sample was collected, in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane, in order that the tests at the experimental mine might approximate the mine conditions.

Six standard face samples were taken from the mine. The results of an analysis of these samples are given in the following table:

Results of analyses of face samples of coal from No. 5 seam, Indiana.

Laboratory No.	Analysis as received.				Ratio $\frac{V}{V+FC}$	Ash plus moisture.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>		<i>Per ct.</i>
23113	11.77	39.16	39.96	9.21	49.55	20.96
23114	11.09	39.42	39.37	9.52	50.03	21.21
23115	10.39	40.53	41.48	7.80	49.29	18.19
23116	11.61	38.72	39.54	10.08	49.16	22.24
24063	9.95	39.93	40.02	10.10	49.94	20.05
24064	9.77	39.71	39.94	10.58	49.86	20.35

The average of the analyses of these face samples as received is as follows:

Average results of analyses of face samples.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....per cent..	10.86
Volatile matter.....do....	39.46
Fixed carbon.....do....	40.04
Ash.....do.....	9.64
Moisture plus ash.....do....	20.50
Ratio of volatile to total combustible.....do.....	49.64

Ultimate analysis:

Hydrogen.....per cent..	5.77
Carbon.....do....	63.77
Nitrogen.....do....	1.10
Oxygen.....do....	15.64
Sulphur.....do....	3.36
Ash.....do....	10.36

Ten road-dust and four rib-dust samples were obtained. The results of analyses and sizing tests of the road and rib dusts are given in the following tables:

Results of analyses and sizing tests of road dusts and rib dusts from mine in Indiana working No. 5 seam.

Laboratory No. of sample.	Kind of dust.	Analysis as received.				Ash plus moisture.	Ratio $\frac{V}{V+FC}$	Sizing tests; cumulative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>P. ct.</i>	<i>Per cent.</i>			
21761.....	Road dust	13.52	31.52	38.09	16.57	30.09	45.51	.....	.....
21762.....	do.	10.00	38.56	38.99	17.43	27.43	46.27	.....	.....
21763.....	do.	8.14	33.15	38.61	20.10	25.24	46.19	.....	.....
24044.....	do.	10.61	32.01	31.52	25.86	36.47	50.39	.....	.....
24045.....	do.	11.96	28.83	33.12	26.07	38.05	46.53	38.6	28.6
24046.....	do.	8.40	24.24	39.96	17.40	25.80	46.15	37.8	27.7
24047.....	do.	12.88	24.77	25.14	37.71	60.09	49.63	32.5	21.0
24053.....	do.	14.09	30.44	24.47	21.00	35.09	46.89	27.0	19.0
24054.....	do.	4.55	14.13	14.06	67.27	71.82	50.15	22.3	14.2
24062.....	do.	9.76	24.41	25.51	40.32	60.08	48.90	38.2	25.7
Av.....	do.	10.34	28.74	31.95	28.97	39.31	47.66	33.0	22.2
24049.....	Rib dust.	24.43	28.96	34.81	11.80	36.23	45.41	48.5	34.7
24050.....	do.	18.02	31.48	34.53	15.97	33.99	47.60	52.3	28.7
24051.....	do.	13.79	25.99	28.08	32.14	45.93	48.07	40.0	25.4
24052.....	do.	13.35	33.23	30.21	23.21	36.56	52.38	39.8	24.8
Av.....	do.	17.40	29.91	31.91	20.78	38.18	48.38	45.1	28.4

In the road-dust samples the content of ash plus moisture ranged from 25.80 to 71.82 per cent, the average being 39.32 per cent; the proportion of 200-mesh dust varied from 14.2 to 27.7 per cent, averaging 22.21 per cent.

In the rib-dust samples the content of ash plus moisture ranged from 33.99 to 45.93 per cent, the average being 38.18 per cent; the proportion of 200-mesh dust varied from 14.2 to 27.7 per cent, averaging 28.4 per cent.

Seven samples of mine air were collected and analyzed, with the following results:

Data on air samples collected in mine in Indiana working No. 5 seam.

Laboratory No. of sample.	Ventilating conditions at point of sampling.	Methane.
		<i>Per cent.</i>
7079	Sample taken in still air.....	0.07
7080	do.....	.43
7082	do.....	.86
7060	Sample collected in main return.....	.18
7061	do.....	.23
7062	do.....	.27

These analyses show that there was little methane in the return air at the time the samples were taken.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Four ignition tests were made with pulverized dust, three without gas, and one with 0.8 per cent gas in the mine air. One propagation test was made with pulverized dust, no gas being used in this test.

Three propagation tests were made with 20-mesh dust, of which 40 per cent would pass 200-mesh, no gas being used in any of these tests.

The average results of analyses and screen tests of the coal dust prepared from the Indiana No. 5 coal used in the tests were as follows:

Average composition and fineness of the coal dust prepared from the No. 5 coal, Indiana.

Proximate analysis:	Pulverized dust.	20-mesh dust.
Moisture.....per cent..	5.10	9.07
Volatile matter.....do....	41.75	39.00
Fixed carbon.....do....	42.29	41.17
Ash.....do....	10.86	10.76
Fineness, cumulative percentage through—		
100-mesh screen.....do....	97.2	62.5
200-mesh screen.....do....	64.0	38.8

Pit shale was used in the tests the incombustible content of which was more than 99 per cent. The 20-mesh shale dust mixed with the coarse coal dust averaged about 30 per cent through 200-mesh

The results of the tests are presented in Table 23.

DISCUSSION OF RESULTS.

TESTS WITH PULVERIZED DUST.

In the ignition series ignition was obtained (test 292) with a mixture of 50 per cent pulverized coal dust and 50 per cent pulverized shale dust, but was not obtained (test 297) with a mixture of 40 per cent coal dust and 60 per cent shale dust. Ignition could not be obtained (test 294) with a mixture of 30 per cent coal dust and 70 per cent shale dust even when there was an average of 0.8 per cent natural gas in the air current. Propagation was obtained (test 298) through a mixture of 30 per cent pulverized coal dust and 70 per cent pulverized shale dust, but with such low pressures and low velocities as to indicate that a small increase in the percentage of pulverized shale dust would probably prevent propagation.

TESTS WITH 20-MESH DUST.

Three propagation tests were made with 20-mesh coal dust, of which 40 per cent would pass through 200-mesh. Propagation was obtained with a 40 per cent coal dust and 60 per cent shale dust mixture (test 302), but not with a 30 per cent coal dust and 70 per cent shale mixture (test 303), no gas being used in either test.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

Under the ignition conditions in the tests at the experimental mine, at least 60 per cent pulverized shale dust is required to prevent ignition through a mixture of pulverized shale dust and pulverized coal dust. A mixture of 70 per cent pulverized shale dust will not permit ignition in the presence of 0.8 per cent gas.

Propagation probably can not be obtained with a mixture of 25 per cent pulverized coal dust and 75 per cent pulverized shale dust.

With 20-mesh coal dust, of which 40 per cent would pass 200-mesh—this is a larger proportion of 200-mesh dust than was present in any of the samples of road dust obtained in the field—propagation could not be obtained with a mixture containing 70 per cent coarse shale dust, all of which would pass through 20-mesh and about 30 per cent of which would pass through 200-mesh; therefore it is probable that a mixture containing 70 per cent, or more, of shale dust is nonexplosive when there is little or no gas present in the air current. If as much as 1 per cent gas is present, probably 5 per cent more of shale dust would be required to prevent propagation.

TABLE 23.—*Results of standard tests of coal dust from the No. 5 bed, Indiana.*

[Originating cause: Standard blown-out shot from cannon at station E 1900. Size of coal dust used: 20-mesh dust, of which 40 per cent would pass 200-mesh, and pulverised dust. Size of pit-dust used: 20-mesh and pulverised.]

IGNITION TESTS.

(Mixed-dust zone: Stations E 1900 to E 940, 350 feet; Stations E 1250 to A 940, 350 feet; total length, 700 feet.)

Test No.	Date.	Size of dust used	Mixed dust.				Natural gas used.	Record obtained in entry or in air course.	Maximum pressure.		Time of tin-fall ruptures at stations and flame velocity between stations.						Length of flame in mixed-dust station zone.	Remarks.
			Ratio of coal dust to shale dust in mixture.	Calculated combustible.	Rate of loading.	Total loading.			Mixture in coal dust.	Station 1150.	Station 950.	Fall at station 1250.	Velocity. 1150.	Fall at station 1050.	Velocity.	Fall at station 950.		
222 ^c	1916 Feb. 29	Pulverised.	80:50	Per cent. 57.6	Lbs. per ft. 4.00	Lbs. 2,800	Per cent. 4.74	Per cent. 0.0	Lbs. at sq. ft. 27 21	Lbs. per sq. ft. 38 31	Sec. on ds. 0.677	Ft. per sec. 173	Sec. on ds. 1.256	Ft. per sec. 583	Sec. on ds. 1.427	Ft. per sec. 2,632	Sec. on ds. 1.465	Ignition obtained.
227	Mar. 10	do	40:60	66.9	5.0	3,500	6.08	.0	1 1	1 1	1.478	39	4.052	3.180	1.410	2,439	1.451	
233	Mar. 3	do	30:70	74.6	3.33	2,323	4.91	.0	1 1	1 1	2.112	1	1	1	1	1	1	Ignition not obtained.
234	do	do	30:70	74.6	3.33	2,323	5.15	.82	1 1	1 1	1	1	1	1	1	1	1	

PROPAGATION TESTS.

(Ignition zone: Pulverized Pittsburgh coal dust, Stations E 1300 to E 1250. Mixed-dust zone: Stations E 1250 to E 950, 300 feet; stations E 1250 to A 950, 350 feet; total length, 650 feet.)

1916.	Pulver- ized.	30:70	74.8	3.33	2,167	5.69	0.0	{Entry..... {Air course.	2	2	.432	128	1.213 1.203	115 168	2.080 1.800	84 221	3.273 2.253	{(e)	Propagation ob- tained.
296	Mar. 13								2	2									
301c	Mar. 20	50:50	58.8	2.0	1,300	8.84	.0	{Entry..... {Air course.	19 17	19 32	.415 .	392	.670 .648	549 442	.892 .874	549 1,136	1.084 1.963	{(e)	Do.
302	Mar. 22	40:60	67.9	2.50	1,625	9.01	.0	{Entry..... {Air course.	12 6	10 16	.419 .	402	.668 .726	800 317	1.001 1.041	459 1,190	1.219 1.136	{(e)	Do.
303	Mar. 24	30:70	76.0	(b)	1,500	9.36	.0	{Entry..... {Air course.	1 1	1 2	.37 .	189	.90 1.04	30 116	4.19 1.90	.....	175 300	Propagation not ob- tained. On ac- count of lack of dust, the mixed dust was loaded at the rate of 3.33 pounds per foot from station E 1250 to stations E 1150 and A 1150 and at 1.87 pounds per foot in re- mainder of zones.	

Flame extended through zones.

^b See "Remarks."

Flame velocity and pressure curves of test are shown in figure 67 (test 292) and figure 3 (test 301).

APPLICATION TO FIELD CONDITIONS.

A mixture of 70 per cent shale dust and 30 per cent coal dust has a moisture and ash content of about 75 per cent. The road-dust samples from this mine, if dry enough to be blown into a cloud, would be explosive, because the percentage of incombustible is not high enough to make the dust nonexplosive. To render these dusts nonexplosive when dry would require the addition of an inert dust to that already in the mine in the following ratio:

Data showing additions of inert material required to make the mine dusts nonexplosive.

Laboratory No. of sample.	Kind of dust.	Moisture and ash content (from analysis).	Desired percentage of incombustible.	Ratio of incombustible material to be added to dust already in mine.
		<i>Per cent.</i>		
21761	Road dust....	30.09	75	1.80
21762	do.....	27.43	75	1.90
21763	do.....	28.24	75	1.87
24044	do.....	36.47	75	1.54
24045	do.....	38.05	75	1.48
24046	do.....	25.80	75	1.97
24047	do.....	50.09	75	1.00
24053	do.....	25.09	75	1.90
24054	do.....	71.52	75	.13
24052	do.....	50.08	75	1.00
24049	Rib dust.....	36.23	75	1.55
24050	do.....	33.99	75	1.64
24051	do.....	45.93	75	1.16
24052	do.....	36.56	75	1.54

In applying the results of tests at the experimental mine to field conditions it will be noted that moisture content in the mixtures tested is decidedly less than that in the road-dust samples, which averaged 10.3 per cent. This increased quantity of moisture probably has some influence in making more difficult the formation of a dense cloud of dust, but experimental tests have shown that coal dust having this percentage of moisture will propagate an explosion and that the total proportion of incombustible dust required to prevent propagation is almost as large as that required when the moisture content is much lower. Hence the presence of the excess moisture would permit little if any decrease in the percentage of incombustible dust required unless the moisture content is raised to a point where the dust is saturated.

Therefore in order to render the mine dust nonexplosive an analysis of that portion of the dust passing through a 20-mesh screen (openings about one-thirtieth inch) should show at least 70 to 75 per cent of ash plus moisture; or, if dependence is placed on wetting for rendering the coal dust inert, the dust should be kept thoroughly

wetted by frequent washings, the washings being done in such a manner as to remove all fine dust from the timbers and ledges. The dust should be wet enough to be pasty when squeezed in the hand.

EXPLOSIBILITY TESTS OF COAL DUST FROM VANCOUVER ISLAND, BRITISH COLUMBIA.

GENERAL CHARACTER OF TESTS.

A series of ten explosion tests was made on 20-mesh dust and pulverized dust prepared from a 5-ton sample of coal from a Vancouver Island mine. The object of this series was to determine the percentages of shale dust necessary to prevent ignition and the propagation of an explosion under standard test conditions both with and without gas in the ventilating current. One set of tests was made with dust crushed to the standard size nearest to the size of dust found in the mine from which the coal was taken. A second set was made with pulverized dust to obtain the maximum explosibility of the coal in order to make comparison with coals from other seams. The testing of this coal and that from Crow's Nest Pass district (see p. 282) was undertaken by request of the Department of Mines of British Columbia, and the samples were taken by one of its inspectors of mines and were submitted to the U. S. Bureau of Mines. The method of taking the samples was not reported.

CONDITIONS IN MINE FROM WHICH SAMPLE WAS TAKEN.

Five reported face samples and four road-dust samples were obtained from the mine from which the large coal sample was taken. The object of taking these samples was to obtain information as to the composition of the coal and the fineness and purity of the road dusts so that the tests at the experimental mine might approximate the mine conditions.

The analyses of the reported face samples are given in the following table:

Results of analyses of face samples of coal from a Vancouver Island mine.

Laboratory Nos. of sample.	Analysis as received.				Ratio V V+FC	Moisture and ash.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>
27338	3.78	37.73	39.50	18.99	48.88	22.77
27339	3.12	37.77	40.20	12.91	44.99	16.03
27340	3.80	40.83	45.91	9.46	47.07	13.26
27341	3.98	38.27	48.84	8.91	43.94	12.89
27342	2.74	40.97	49.82	6.47	45.13	9.21

The analysis of a composite of these five samples is as follows:

Results of analysis of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....	per cent..	3.48
Volatile matter.....	do....	39.44
Fixed carbon.....	do....	45.81
Ash.....	do....	11.27
Moisture plus ash.....	do....	14.75
Ration of volatile to total combustible.....	per cent..	46.26

Ultimate analysis:

Hydrogen.....	per cent..	5.01
Carbon.....	do....	69.03
Nitrogen.....	do....	1.16
Oxygen.....	do....	12.57
Sulphur.....	do....	.96
Ash.....	do....	11.27

The analysis and screen tests of the road-dust samples are as follows:

Results of analyses and screen tests of road-dust samples from mine in Vancouver Island.

Laboratory No. of sample.	Analysis as received.				Moisture and ash.	Ratio $\frac{V}{V+FC}$	Sizing test, cumulative percentage through—	
	Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
27344	3.43	34.77	33.47	28.33	31.76	50.96	26.3	15.0
27345	5.86	31.46	31.49	31.19	37.05	49.98	23.8	10.4
27346	11.30	34.10	34.57	20.03	31.33	49.65	73.1	47.3
27347	6.92	32.06	30.10	30.90	37.83	51.59	19.1	9.0
Av....	6.88	33.10	32.41	27.61	34.49	50.54	35.6	20.4

In the road-dust samples the content of moisture plus ash varied from 31.33 to 37.82 per cent, the average being 34.49 per cent; the content of 200-mesh dust ranged from 9.0 to 47.3 per cent, the average being 20.4 per cent.

No rib-dust samples were taken from this mine. It is known that the mine gives off considerable gas, but no samples of the mine air were submitted.

It was decided that 20-mesh dust of which 20 per cent would pass 200-mesh was the nearest standard size to the dust in this mine; therefore this size was used in the explosion tests at the experimental mine.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Two ignition tests and one propagation test were made with pulverized coal dust, all without gas. Two ignition tests and two propagation tests were made with 20-mesh coal dust of which 20 per cent would pass 200-mesh, no gas being used in these tests. Three propagation tests were made with 20-mesh coal dust of which 20 per cent would pass 200-mesh, with gas present in the air current in proportions ranging from 1.09 to 2.22 per cent.

The average analyses of the pulverized coal dust and of the 20-mesh coal dust used in the tests were as follows:

Average analyses of pulverized and of 20-mesh coal dust used.

		Pulverized coal dust.	20-mesh coal dust.
Moisture.....	per cent..	2. 61	2. 85
Volatile matter.....	do.....	38. 56	38. 40
Fixed carbon.....	do.....	43. 39	44. 03
Ash.....	do.....	15. 44	14. 72
Ratio of volatile to total combustible.....		47. 08	46. 68

The average analysis of the pit-shale dust used showed 1.39 per cent moisture and 99.66 per cent total incombustible.

The average results of sizing tests of the coal and shale were as follows:

Average results of sizing tests of coal dust and shale dust used.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	Per cent.	Per cent.	Per cent.	Per cent.
Pulverized coal dust.....	98.3	70.4	98.9	81.8
20-mesh coal dust.....			38.0	20.0
Pulverized shale dust.....			99.9	92.8
20-mesh shale dust.....	86.6	60.1	37.4	26.9

The average sizing tests of the pulverized Pittsburgh coal dust used in the ignition zone of the propagation tests showed 98.7 per cent through 100-mesh and 82.1 per cent through 200-mesh. The average analysis of this coal gave a moisture plus ash content of 6.20 per cent and a ratio of volatile combustible to total combustible of 40.88 per cent.

Table 24, showing the results of the explosion tests, follows:

TABLE 24.—Results of standard tests of coal dust from Vancouver Island, British Columbia.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Sizes of coal dust used, 20-mesh dust, of which 20 per cent would pass 20-mesh, and pulverized dust; sizes of pit-shale dust used, 20-mesh, and pulverized. In the ignition tests the rate of mixed-dust loading in the first 50 feet was twice that used in the rest of the zone and given in the table; the mixed-dust zone extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250; the mixed-dust zone extended from stations E 1250 to A 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
				Calculated incombustible.	Rate of loading.	Total loading.		Station 1150.	Station 950.	Foil at station 1250.	Ve-locity 1250.	Foil at station 1150.	Ve-locity 1150.	Foil at station 1050.	Ve-locity 1050.	Foil at station 950.	
404 ^c	1917. Mar. 30	(Pulver-ized.)	50:50	Per cent. 58.0	Lbs. per ft. 2.00	Lbs. 1,500	Per cent. 0.0	Lbs. per sq. ft. 19	Lbs. per sq. ft. 19	Sec. onds. 1:112	Feet per sec. 245	Sec. onds. 1:320	Feet per sec. 531	Sec. onds. 1:713	Feet per sec. 909	Sec. onds. 1:822	Ignition obtained.
							{Air course.	16	24	.....	1:360	.....	400	1:640	1,754	1,667	
399	Mar. 23	do....	40:60	67.9	2.50	1,875	.0	1	1	1:807	.....	.....	.....	.....	.....	.....	Ignition not obtained.
397	Mar. 21	20-mesh	70:30	42.3	1.43	1,069	.0	1	1	3:281	.....	.....	.....	.....	.....	.....	
392	Mar. 12	do....	80:40	50.3	1.67	1,251	.0	1	1	3:412	.....	.....	.....	.....	.....	.....	Do.
							{Air course.	1	1	.....	.....	.....	.....	.....	.....	.....	

PROPAGATION TESTS.

1917.	400	Mar. 23	Pulver. { 40:60 lized.	67.9	2.50	1,625	0.0	Entry..... Air course.	13 15	13 19	0.423	254	0.816 .781	588 417	0.985 .991	980 1,408	1.085 1.082	(c)	Propagation obtained.
393	Mar. 12	20-mesh	60:40	50.3	1.67	1,063	.0	Entry..... Air course.	6 6	7 8	.371	199	.895 .938	221	1.369	252 621	1.691 1.551	(c)	Do.
394	Mar. 14	do...	50:50	58.6	2.00	1,300	.0	Entry..... Air course.	2 1	2 2	.392	110	1.302 1.142	51	2.250	155 131	2.994 2.686	(c)	Do.
398	Mar. 22	do...	30:70	75.3	3.33	2,167	1.09	Entry..... Air course.	1 1	1 1	.205	104	1.167 1.018	53 77	2.070 2.315	150 275	1.197 1.159	(c)	Propagation not obtained.
395	Mar. 15	do...	30:70	75.5	3.33	2,167	1.83	Entry..... Air course.	8 8	9 8	.268	286	.619 .679	264	.953	427 417	1.197 1.159	(c)	Propagation obtained.
396	Mar. 20	do...	25:75	79.4	4.00	2,600	2.22	Entry..... Air course.	2 1	1 1	.212	114	1.083 .988	62 115	2.719 1.882	300 134	2.607	(c)	Propagation obtained for air course, but not in entry.

a Flame extended through both the entry and the air-course zones.

b Flame extended through the air-course zone.

c Flame velocity and pressure curves of this test are shown in figure 66.

DISCUSSION OF THE RESULTS.

TESTS WITH PULVERIZED DUSTS.

Ignition was obtained in test 404 through a mixture of 50 per cent coal dust and 50 per cent shale dust. Ignition was not obtained in test 399 through a mixture of 40 per cent coal dust and 60 per cent shale dust, the flame traveling only 75 feet into the mixed dust. Propagation was obtained in test 400 through a mixture of 40 per cent coal dust and 60 per cent shale dust. Considerable pressure was registered in this test, and the flame velocities in the last 100 feet were high; therefore it is doubtful whether 10 per cent additional shale would prevent propagation.

TESTS WITH 20-MESH DUST.

Ignition was not obtained in test 397 through a mixture of 70 per cent 20-mesh coal dust and 30 per cent 20-mesh shale dust. No gas was used. The flame extended 150 feet in the air-course zone in this test, and it is probable that with 10 per cent less shale dust present ignition would be obtained. In test 394 propagation was obtained through a mixture of 50 per cent 20-mesh coal and 50 per cent 20-mesh shale dust, there being no gas in the ventilating current. In test 398 propagation was not obtained through a mixture of 30 per cent 20-mesh coal dust and 70 per cent 20-mesh shale dust, with 1.09 per cent gas in the ventilating current. The velocities and pressures were low. From these results, in conjunction with the results of test 393, it is considered probable that propagation would not be obtained with a mixture of 40 per cent coal dust and 60 per cent shale dust without gas present.

In test 395 a mixture of 30 per cent coal and 70 per cent shale dust was tried, with 1.83 per cent gas present, and propagation was obtained. In test 396 the mixture of 25 per cent coal dust and 75 per cent shale dust was used, with 2.22 per cent gas present. Propagation was obtained through the air-course zone with low pressures and velocities, but was not obtained in the entry zone. It is probable that this mixture would fail to give propagation if the amount of gas present was not more than 2.0 per cent.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

Under the ignition conditions in the experimental-mine tests at least 60 per cent pulverized shale dust is required to prevent ignition through a mixture of pulverized shale dust and pulverized coal dust.

With 20-mesh dust ignition can not be obtained through a mixture of 70 per cent coal dust and 30 per cent shale dust. Propagation probably can not be obtained through a mixture of 40 per cent 20-mesh coal dust and 60 per cent 20-mesh shale dust when there is no gas present. Propagation would be prevented by a mixture of

30 per cent coal dust and 70 per cent shale dust when there is 1 per cent gas present, but a mixture containing at least 75 per cent shale dust would be necessary to prevent propagation in the presence of 2 per cent gas.

The figures for 20-mesh dust apply to coal dust 20 per cent of which would pass 200-mesh. If the coal dust were found to be finer, more shale dust would be required to get the same results.

APPLICATION TO FIELD CONDITIONS.

With this coal the total amount of incombustible necessary in a mixture to prevent ignition or propagation of an explosion under the test conditions is shown in the following table. The total incombustible includes the moisture and ash of the coal, as well as the admixed inert material.

Data showing proportions of inert dust needed to make the coal dust nonexplosive.

Item.	Gas present.	Incombustible in mixture.	Shale in mixture.
	Per cent.	Per cent.	Per cent.
20-mesh coal dust, of which 20 per cent will pass 200-mesh:			
Nonignition.....	0	42	30
Nonpropagation.....	0	57	60
Do.....	1	76	70
Do.....	2	80	75
Pulverized coal dust:			
Nonignition.....	0	68	60

As this mine is known to give off gas, it would be better to have 80 per cent incombustible present in the road dusts, because this would take care of 2 per cent of gas present. Examination of the table of road dusts shows that none of the samples have this amount of incombustible (moisture plus ash); consequently all of them are explosive. In determining the content of moisture plus ash in the road dusts only that portion of the dust which passes 20-mesh should be considered. The following table shows the ratio of inert dust that would have to be added to that already in the mine-road dusts to render them nonexplosive:

Data showing additional amount of inert dust necessary.

Laboratory No. of sample.	Moisture plus ash (from analysis).	Desired percentage of incombustible.	Ratio of incombustible material to be added.
	Per cent.		
27344	31.76	80	2.41
27345	37.05	80	2.15
27346	31.33	80	2.43
27347	37.82	80	2.11

Therefore in order that the mine dust be nonexplosive in the presence of 2 per cent gas an analysis of that portion of the dust passing through a 20-mesh screen should show 80 per cent or more of moisture plus ash, or, if dependence is placed on wetting for rendering the coal dust inert, it should be thoroughly wetted by frequent washing in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM NO. 4 BED, MONTANA.

GENERAL CHARACTER OF EXPLOSION TESTS.

A series of 14 explosion tests was made on 20-mesh and pulverized dusts prepared from a 4-ton sample of coal from a mine in Montana working the "No. 4" seam. The object of this series was to determine the percentages of shale necessary to prevent ignition and to prevent propagation of an explosion under standard test conditions both with and without gas in the ventilating current. One set of tests was made with 20-mesh dust, 20 per cent of which would pass 200-mesh, this being the standard size nearest to that of the dust found in the mine. A second set was made with pulverized dust to obtain the maximum explosibility of the coal in order to make the comparisons with coal from other mines.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Examination was made of the conditions in the mine from which this sample was taken in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane, so that the tests at the experimental mine might approximate the actual mine conditions.

Four standard face samples were obtained, the analyses of these samples being given in the following table:

Results of analyses of face samples of coal from mine in Montana working the "No. 4" seam.

Laboratory No. of sample.	Analyses as received.				Ratio $\frac{V}{V+FC}$.	Content of moisture plus ash.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>
29466	11.28	33.61	44.61	10.60	43.02	21.88
29467	11.12	33.62	44.61	10.45	42.87	21.57
29468	11.20	35.07	40.40	13.33	46.46	24.58
29469	9.89	35.14	42.26	12.71	45.40	22.60

The analysis of a composite of these face samples is as follows:

Results of analysis of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....per cent..	10.77
Volatile matter.....do....	34.21
Fixed carbon.....do....	43.17
Ash.....do....	11.85
Moisture plus ash.....do....	22.62
Ratio of volatile to total combustible.....per cent..	44.21

Ultimate analysis:

Hydrogen.....per cent..	5.25
Carbon.....do....	59.25
Nitrogen.....do....	1.28
Oxygen.....do....	21.37
Sulphur.....do....	1.00
Ash.....do....	11.85

Four road-dust and three rib-dust samples were obtained. Analyses and sizing tests of these samples are given in the following table:

Results of analyses and screen tests of road-dust and rib-dust samples from mine in Montana working the No. 4 seam.

Laboratory No. of sample.	Kind of dust.	Analyses as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$.	Screen test of ma- terial passing 20- mesh screen; cumulative per- centage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
29215....	Road dust.	<i>Per cent.</i> 18.09	<i>Per cent.</i> 28.62	<i>Per cent.</i> 34.57	<i>Per cent.</i> 18.73	<i>Per cent.</i> 36.81	45.29	6.6	2.8
29216....	do.....	10.94	21.93	19.39	47.74	58.68	53.06	30.2	17.6
29214....	do.....	11.88	31.45	35.69	20.98	32.86	46.84	29.1	15.4
29219....	do.....	10.73	33.01	31.07	25.19	35.92	51.82	25.9	4.7
29217....	Rib dust.	15.28	31.63	27.91	25.18	40.46	53.13	74.9	58.4
29471....	do.....	12.63	32.43	38.12	16.82	29.45	45.97	29.6	15.3
29472....	do.....	10.66	31.37	34.82	23.26	33.91	47.32	36.6	19.0

In the road-dust samples the content of ash plus moisture ranged from 32.86 to 58.68 per cent, the average being 41.07 per cent. The proportion of 200-mesh dust varied from 2.8 to 17.6 per cent, the average being 10.1 per cent.

In the rib-dust samples the content of ash plus moisture ranged from 29.45 to 40.46 per cent, the average being 34.61 per cent. The proportion of 200-mesh dust varied from 15.3 to 58.4 per cent, the average being 30.9 per cent.

Methane was being given off in one part of the mine, but in small quantities only, and could be removed easily by proper ventilation.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Seven ignition tests were made, all with 20-mesh dust. Four of these were without gas and three with additions of gas ranging from 1.5 to 2 per cent. Four propagation tests were made with 20-mesh dust, two without gas, and two with 1.0 per cent and 1.9 per cent,

respectively. Three propagation tests were made with pulverized dust, two without gas, and one with 0.9 per cent gas.

The average analyses of the 20-mesh dust and the 100-mesh dust prepared from the "No. 4" seam coal just before mixing for the tests were as follows:

Average of analyses of 20-mesh and 100-mesh dust from "No. 4" coal.

		20-mesh coal dust.	100-mesh coal dust.
Moisture.....	per cent..	9.77	8.12
Volatile matter.....	do....	34.82	35.53
Fixed carbon.....	do....	42.68	42.44
Ash.....	do....	12.73	13.91
		100.00	100.00
Ratio of volatile to total combustible.....		44.93	45.50

The average analysis of the shale dust used in these tests showed a moisture content of 1.31 per cent and of total incombustible 99.30 per cent.

The average sizing tests of the coal and shale were as follows:

Average results of sizing tests of coal dust and shale dust used.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	Per cent.	Per cent.	Per cent.	Per cent.
20-mesh coal dust.....	98.2	67.7	37.2	20.0
Pulverized coal dust.....			99.6	88.0
20-mesh shale dust.....	98.8	70.6	47.7	35.1
Pulverized shale dust.....			99.8	98.0

The average sizing test on the pulverized Pittsburgh coal dust used in the ignition zone of propagation tests showed 99.7 per cent through 100-mesh and 85.3 per cent through 200-mesh. The average analysis of this Pittsburgh coal dust gave a moisture and ash content of 5.95 per cent and a ratio of volatile combustible to total combustible of 40.54.

The results of the tests are presented in Table 25, page 240.

DISCUSSION OF RESULTS.

IGNITION TESTS WITHOUT GAS.

Ignition was not obtained in test 449 with pure 20-mesh coal dust containing 17.8 per cent moisture, but was obtained in test 450 when there was only 9.9 per cent moisture present. The low pressures obtained in the latter test indicate that ignition would not be obtained if 20 per cent shale were added to this second sample of pure dust. In test 447 ignition was not obtained with a mixture containing 12.8 per cent moisture and 45.1 per cent total incombustible (25 per cent shale), the flame traveling only 50 feet from the cannon.

IGNITION TESTS WITH GAS.

Ignition was not obtained in test 448 with a mixture containing 12 per cent moisture and 45.1 per cent total incombustible (25 per cent shale) when there was 1.5 per cent gas in the ventilating current, but in test 454, with practically the same mixture, containing 9.6 per cent moisture and 46.8 per cent total incombustible (28 per cent shale), a strong ignition was obtained with 2 per cent of gas in the ventilating current, the pressures at the outby ends of the two test zones being 19 and 21 pounds, respectively, per square inch.

Ignition was not obtained in test 455 with a mixture containing 7.8 per cent moisture and 54.6 per cent total incombustible (39 per cent shale), with 1.7 per cent gas in the ventilating current. As the flame traveled 200 feet in this test, ignition would be obtained with a slight increase in the percentage of gas present or a decrease in the percentage of moisture or incombustible.

PROPAGATION TESTS WITH 20-MESH DUST.

Propagation was obtained in test 452 with a mixture containing 7.8 per cent moisture and 62.0 per cent total incombustible (48 per cent shale), with no gas in the ventilating current. The low pressures and velocities obtained in this test indicate that an additional 10 per cent of shale would prevent propagation. A strong propagation was obtained in test 451 with a mixture containing 9.9 per cent moisture and 60.7 per cent total incombustible (46 per cent shale), with 1 per cent of gas in the ventilating current. Propagation was also obtained in test 453 with a mixture containing 5.5 per cent moisture and 77.2 per cent total incombustible (69 per cent shale), with 1.9 per cent gas in the ventilating current. The low pressures and velocities obtained in this test indicate that a slightly lower percentage of gas or a greater percentage of incombustible would prevent propagation.

PROPAGATION TESTS WITH PULVERIZED DUST.

Propagation was obtained in test 456 with a mixture containing 3.5 per cent moisture and 76.1 per cent total incombustible (70 per cent shale), with no gas, but propagation was not obtained in test 457 when the total incombustible was raised to 79.5 per cent (75 per cent shale), although the moisture content of the mixture was only 2.6 per cent. Propagation was not obtained in test 458 with a mixture containing 2.4 per cent moisture and 84.3 per cent total incombustible (80 per cent shale) with 0.9 per cent gas in the ventilating current, but the flame extended nearly to the end of the air course zone.

TABLE 25.—Results of standard tests of coal dust from the "No. 4" bed, Montana.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used, 20-mesh, 20 per cent of which would pass 200-mesh, and pulverized. Size of pit-shale dust used, 20-mesh, and pulverized. In the ignition tests the rate of mixed dust loaded in the first 50 feet was twice that used in the rest of the zone and as given in the table; the mixed-dust zone extended from stations E 1300 to E 950, 350 feet; and from stations E 1250 to E 950, 300 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250; the mixed-dust zone extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Charac-ter of mixture.	Mixed dust.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.	
				Mols-ture.	Calcu-lated uncom-bus-tible.	Rate of load-ing.		Total load-ing.	Natu-rals gas used.	Sta-tion 1150.	Sta-tion 950.	Foil at station locity. 1250.	Foil at station locity. 1150.	Foil at station locity. 1050.	Foil at station locity. 950.			
450	1918. Feb. 1	20-mesh	100 coal.	Per cent. 9.9	Per cent. 21.7	Lbs. 1.00	Lbs. 750	Per cent. 0.0	Entry..... Air course.....	Lbs. per sq. in. 7 5 6	Sec-onds. 0.603	Sec-onds. 1.941	Sec-onds. 173	Sec-onds. 2,514	Sec-onds. 403	Sec-onds. 2,717	Fict. (b)	{ Ignition ob-tained.
449	Jan. 30	do.	63 coal. { 7 water.	17.8	26.9	1.07	807	.0	Entry..... Air course.....	1 1 1 1							75 75		{ Ignition not obtained.
447	Jan. 28	do.	70 coal. { 25 shale. 5 water.	12.8	45.1	1.43	1,071	.0	Entry..... Air course.....	1 1 1 1	2.527	.....	.....	.....	.....	.....	50	{ Do.
445	Jan. 23	do.	60 coal. { 30 shale. 5 water.	11.2	53.4	1.67	1,260	.0	Entry..... Air course.....	1 1 1 1							50		{ Do.
448	Jan. 28	do.	70 coal. { 25 shale. 5 water.	12.0	45.1	1.43	1,071	1.5	Entry..... Air course.....	2 1 2 1	2.670	379	2.934	.....	.....	.....	150 275	{ Do.
454	Feb. 11	do.	70 coal. { 26 shale. 2 water.	9.6	46.8	1.43	1,071	2.0	Entry..... Air course.....	18 19 14 21	7.53	116	1.617	420	1.865	1,987	1.918		{ (b) Ignition ob-tained.
455	Feb. 13	do.	60 coal. { 36 shale. 1 water.	7.8	54.6	1.67	1,250	1.7	Entry..... Air course.....	2 1 2 1	.808	47	2.927	.....	.....	.....	160 250	{ Ignition not obtained.

PROPAGATION TESTS.

1918. Jan. 23	446	20-mesh do.	69 coal.. 35 shale.. 5 water..	8.1	53.4	1.67	1,083	0.0	Entry..... Air course.	4 4	4 3	0.421	85 1.598 1.195	215 184 1.738	2,063 126 2,532	140 2,775 2,532	(b)	{Propagation ob- tained.
Feb. 6	452	do.	50 coal.. 48 shale.. 2 water..	7.8	62.0	2.00	1,300	.0	Entry..... Air course.	2 2	2 2	.423	78 1.700 1.680	115 2,567	95 660 2,183	(b)	Do.	
Feb. 4	451	do.	50 coal.. 46 shale.. 4 water..	9.9	60.7	2.00	1,300	1.0	Entry..... Air course.	7 7	8 7	.241	161 .862 .791	369 232 1.222	1,133 316 1,538	1,449 1,287	(b)	Do.
Feb. 8	453	do.	30 coal.. 69 shale.. 1 water..	5.5	77.2	3.38	2,167	1.9	Entry..... Air course.	2 2	2 2	.325	122 1.144 .882	80 2,401	144 2,268	325 (b)	{Propagation ob- tained in air course, but not in entry.	
Feb. 16	456	Pulver- ized.	30 coal.. 70 shale..	3.5	76.1	3.33	2,167	.0	Entry..... Air course.	9 9	9 12	.271	160 .927 .841	526 337 1.138	1,117 377 971	1,382 1,241	(b)	{Propagation ob- tained.
Feb. 18	457	do.	25 coal.. 75 shale..	2.6	79.5	4.00	2,600	.0	Entry..... Air course.	1 1	1 1	.317	104 1.278 2.871	2 2,560	100 250	100 250	{Propagation not obtained.	
Feb. 20	458	do.	20 coal.. 80 shale..	2.4	84.3	5.00	3,250	1.9	Entry..... Air course.	2 1	1 1	..... .....	1.181 1.385	35 4,043 1,385	91 2,498 300	150 300	Do.	

• Figures indicate percentages.

• Flame extended through zones.

• Flame velocity and pressure curves of this test are shown in figure 63.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

The total amount of incombustible necessary in a mixture with this coal to prevent ignition or propagation of an explosion under the test conditions is shown in the following table. These figures are based upon coal with at least 10 per cent moisture. The total incombustible includes the moisture and ash of the coal, as well as the admixed inert material.

Data showing proportions of incombustible required to render nonexplosive the coal dust from No. 4 seam, Montana.

Item.	Gas present.	Total incombustible.	Shale in mixture.
20-mesh coal dust of which 20 per cent will pass through 200-mesh:	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Nonignition.....	0	46	30
Do.....	1	54	40
Do.....	2	62	50
Nonpropagation.....	0	69	60
Do.....	1	77	70
Do.....	2	81	75
100-mesh coal dust, of which 85 per cent will pass through 200-mesh (pulverized):			
Nonpropagation.....	0	80	75
Do.....	1	84	80

APPLICATION TO FIELD CONDITIONS.

As a small amount of methane was found in this mine, the total incombustible needed in order to have a mixture which will not propagate an explosion must be somewhat higher than if there were no gas.

An incombustible content of 69 per cent will prevent propagation when there is no gas in the air current, and 75 per cent might be considered a safe limit, provided that not more than 0.5 per cent was in the air current. It will be observed that none of the road and rib dusts obtained have this much moisture plus ash, and consequently all would propagate an explosion. To render these dusts nonexplosive when dry would require the addition of an inert dust to that already in the mine in the following ratios:

Data showing additions of inert dust needed to make the road and rib dusts nonexplosive.

Laboratory No. of sample.	Kind of dust.	Moisture plus ash (from analysis).	Desired percentage of incombustible.	Ratio of incombustible material to be added to dust already in the mine.
		<i>Per cent.</i>		
29215	Road dust....	36.81	75	1.53
29216	do.....	53.68	75	0.65
29214	do.....	32.86	75	1.69
29219	do.....	35.92	75	1.56
29217	Rib dust.....	40.46	75	1.33
29471	do.....	39.45	75	1.32
29472	do.....	33.91	75	1.64

In applying these results it should be remembered that they apply to coal dust containing 10 per cent or more of moisture. This coal normally contains about that amount of water, but will lose a considerable part thereof when broken up and exposed to dry air.

Therefore, in order that the mine dust be nonexplosive the analysis of that portion of the dust passing a 20-mesh screen should show at least 75 per cent of moisture plus ash, or if dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washing in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE NO. 6 BED, SOUTHERN ILLINOIS.

GENERAL CHARACTER OF THE EXPLOSION TESTS.

A series of 12 explosion tests was made on 20-mesh and pulverized dusts prepared from a 5-ton sample of run-of-mine coal obtained from a mine in Illinois working the No. 6 seam. The pulverized dust was used in tests to determine the relative explosibility of dust from this coal as compared with coal dust from other beds. The 20-mesh dust was used in tests to determine whether dust comparable in size and incombustible content to that found in this mine could sustain an explosion. The 20-mesh coal dust used contained about 20 per cent of 200-mesh dust, this being the standard size nearest to the size of the road and rib dusts found in the mine. The two standard classes of tests—ignition and propagation—were made.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Conditions were examined in the mine from which this sample was obtained in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane, that the tests at the experimental mine might approximate the mine conditions.

Six standard face samples were taken, the analyses being given in the following table:

Results of analyses of face samples of coal from mine in Illinois working the No. 6 seam.

Laboratory No. of sample.	Coal as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
29743	9.28	34.17	48.77	7.78	17.05	41.21
29742	10.34	33.70	46.90	9.06	19.40	41.81
29745	10.56	34.81	44.73	9.90	20.46	43.77
29746	10.36	32.12	47.21	10.31	20.67	40.48
29741	9.73	34.19	48.99	7.09	16.82	41.11
29744	9.17	34.29	49.15	7.39	16.56	41.09

The analysis of a composite of these samples is as follows:

Results of analyses of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....per cent..	9.77
Volatile matter.....do....	34.15
Fixed carbon.....do....	47.45
Ash.....do....	8.63
Moisture plus ash.....do....	18.40
Ratio of volatile to total combustible.....per cent..	41.85

Ultimate analysis:

Hydrogen.....per cent..	5.34
Carbon.....do....	66.23
Nitrogen.....do....	1.51
Oxygen.....do....	17.54
Sulphur.....do....	0.75
Ash.....do....	8.63

Fifteen standard samples of road and rib dust were taken. The results of analyses of these samples are given in the following table:

Results of analyses of road-dust and rib-dust samples from an Illinois mine working the No. 6 seam.

Laboratory No. of sample.	Kind of dust.	Analyses as received.				Moisture plus ash.	Ratio V V+FC	Material passing through 50-mesh screen; cumulative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
29748	Road dust.	2.21	19.82	28.73	49.24	51.45	40.83	21.0	13.6
29749	do.	6.95	21.27	29.40	42.38	49.33	41.96	36.8	24.6
29755	do.	9.20	23.86	27.99	38.95	48.15	46.02	22.6	20.7
29758	do.	10.85	23.15	35.96	30.04	40.89	39.17	25.5	13.7
29759	do.	8.72	15.49	19.06	61.71	65.43	44.81	30.7	19.6
29760	do.	7.05	20.49	31.93	40.53	47.58	39.08	23.8	22.5
29762	do.	9.82	28.96	39.13	22.09	31.91	42.53	36.2	23.1
29765	do.	7.04	25.20	53.05	14.71	21.75	32.20	28.0	27.5
29766	do.	9.25	20.44	29.78	40.53	49.78	40.69	27.5	16.2
29767	do.	12.42	23.11	45.82	18.65	31.07	33.53	58.2	36.6
29750	Rib dust.	14.38	27.20	33.48	24.94	39.32	44.83	56.2	42.3
29751	do.	12.56	30.06	39.31	18.07	30.63	43.32	26.8	15.2
29756	do.	4.94	30.27	25.20	39.59	44.52	54.57	74.6	64.1
29757	do.	7.86	29.24	45.58	17.32	25.18	39.08	22.7	26.0
29761	do.	10.77	27.72	40.76	20.75	31.52	40.48	30.4	19.6

When the weights of the corresponding road and rib dust samples are considered, these samples average about 26 per cent through 200-mesh.

Twenty samples of the mine air were taken. The following are typical of the set.

Results of analyses of mine-air samples from an Illinois coal mine working the No. 6 bed.

Laboratory No. of sample.	Condition of air at place of sampling.	Methane in sample.
9528	Sample taken in still air.....	Per cent.
9530	do.....	0.26
9532	Sample taken in secondary split.....	.25
9542	do.....	.20
9535	Sample collected in main return.....	.15
9541	do.....	.19
9526	do.....	.17

These analyses show a very small percentage of methane in the return air, although measurements showed that the aggregate amount per 24 hours was large. The gas was being taken care of by adequate ventilation

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Three ignition tests were made with 20-mesh coal dust, two being without gas and one with 1.8 per cent of gas.

Eight propagation tests were made with 20-mesh dust, five being without gas and three with additions of gas ranging from 1.1 per cent to 2.2 per cent. Two of the tests without gas were made with 100-mesh No. 6 seam coal in the 50-foot ignition zone instead of the usual Pittsburgh coal dust.

The average analyses of the 20-mesh and 100-mesh (pulverized) No. 6 seam coal dust just before mixing for the tests was as follows:

Results of average analyses of 20-mesh and 100-mesh dusts prepared from No. 6 coal.

	20-mesh dust.	100-mesh dust.
Moisture.....per cent..	8.79	5.47
Volatile matter.....do....	35.06	35.41
Fixed carbon.....do....	48.32	51.70
Ash.....do....	7.83	7.42
	100.00	100.00
Ratio of volatile to total combustible.....	42.05	40.65

The average analyses of the shale dust used in these tests showed: Moisture, 1.37 per cent; total incombustible, 99.30 per cent.

The average sizing tests of the coal dust and shale dust is as follows:

Results of average sizing tests of coal dust and shale dust used.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	Per cent.	Per cent.	Per cent.	Per cent.
20-mesh coal dust.....	99.2	66.5	35.0	21.5
Pulverized coal dust.....			99.1	52.7
20-mesh shale dust.....	96.7	83.6	51.5	39.0
Pulverized shale dust.....			99.4	85.4

The average sizing test of the pulverized Pittsburgh coal dust used in the ignition zone in the propagation tests showed 99.4 per cent through 100-mesh and 85.4 per cent through 200-mesh. The average analyses of this coal dust gave a moisture plus ash content of 7.31 per cent and a ratio of volatile combustible to total combustible of 40.69 per cent.

The results of the explosion tests are tabulated in Table 26 herewith:

TABLE 26.—Results of standard tests of coal dust from the No. 6 bed, Illinois.

Originating cause: Standard blown-out shot from cannon at station E 1300. Sizes of coal dust used, 20-mesh dust, 20 per cent of which would pass 20-mesh, and pulverized dust. Sizes of pit-shale dust used, 20-mesh and pulverized. In the ignition tests the rate of mixed-dust loading in the first 50 feet was twice that which was used in the rest of the zone and which is given in the table. The mixed-dust zone extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250; the mixed-dust zone extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Mixed dust.				Records obtained in entry or in air course.	Maximum pressure.		Time of tin-fel rupture at stations and flame velocity between stations.					Length of flame in mixed-dust zone.	Remarks.
			Ratio of coal dust to shale dust in mixture.	Mois- ture con- tent.	Calcu- lated incomb- ustible.	Rate of load- ing.		Total load- ing.	Natu- ral gas used.	Sta- tion 1150.	Sta- tion 950.	Fall at Ve- station locity.	Fall at Ve- station locity.	Fall at Ve- station locity.		
488	1918. May 11	20-mesh	(c)	Per cent.	Per cent.	Lbs. per ft.	Lbs.	Per cent.	Lbs. per sq. in.	Lbs. per sq. in.	Sec- onds.	Feet per sec.	Sec- onds.	Feet per sec.	Feet per sec.	Ignition obtained.
				8.85	16.6	1.00	750	0.0	Entry..... (Air course.....)	11 11	14 14	0.432 0.432	99	1.445 1.328	334 420		932 1.566	1.570 1.686
491	May 18	do.	80:20	7.76	33.1	1.25	938	.0	Entry..... (Air course.....)	1 1	.787	.....	.....	.....	.....	Ignition not ob- tained.
492	May 19	do.	70:30	6.94	41.5	1.43	1,071	1.8	Entry..... (Air course.....)	1 1	1.270	41	3.632 2.481	.....	.....	Do.

PROPAGATION TESTS.

1918.	May 7	20-mesh	70:30	7.12	42.8	1.43	929	0.0	{Entry..... {Air course.	6 11	5	.....	0.837 .832	.....	195 1,346	.....	320 1,433 1,416	{(b)	{Propagation obtained.
486	May 21	do....	60:40	5.61	50.1	1.67	1,083	.0	{Entry..... {Air course.	2 1	2 1	0.339	101 1.328	.....	.....	.....	.....	100 150	{Propagation not obtained.
486	May 6	do....	60:40	6.21	43.7	1.67	1,083	.0	{Entry..... {Air course.	1 1	1 1	.586	56 1.704	.....	81 2,524	.....	.....	75 225	{Propagation not obtained. Pulverized "No. 6 seam" dust used in the ignition zone.
488	Apr. 30	do....	50:50	5.46	58.7	2.00	1,300	.0	{Entry..... {Air course.	1 1	1 1	.277	94 1.204	.....	110 2,112	.....	.....	100 325	{Propagation not obtained.
487	May 10	do....	50:50	5.59	58.2	2.00	1,300	1.1	{Entry..... {Air course.	7 7	8 7	.347	220 .763	.....	324 314	1.056 1.081	373 440	{(b)	{Propagation obtained.
484	May 2	do....	40:60	4.81	66.4	1.67	1,083	.0	{Entry..... {Air course.	1 1	1 1	.321 .....	.....	.....	.....	.....	50 75	{Propagation not obtained. Pulverized "No. 6 seam" dust used in the igni- tion zone.	
489	May 14	do....	40:60	5.18	66.7	2.50	1,625	2.2	{Entry..... {Air course.	8 12	9 8	.305	280 .666	.....	279 309	1.008 1.019	474 2,438	{(b)	{Propagation obtained.
490	May 17	do....	30:70	4.81	75.1	3.33	2,167	1.9	{Entry..... {Air course.	3 2	3 2	.338	135 .973	.....	87	2,122 .....	.....	125 300	{Propagation not obtained.
494	May 22	{Pulver- {Ised.	40:60	2.51	66.0	2.50	1,625	.0	{Entry..... {Air course.	8 9	8 11	.280	106 .934	.....	262 341	1.213 1.227	459 1,587	{(b)	{Propagation obtained.

* All coal.

b Flame extended through zone.

DISCUSSION OF RESULTS.

IGNITION TESTS WITH 20-MESH COAL DUST.

Ignition was obtained in test 488 with pure 20-mesh coal dust containing 16.6 per cent total incombustible, but was not obtained in test 491 with a mixed dust having a total incombustible content of 33.1 per cent (20 per cent shale), no gas being used in either test. Ignition was not obtained in test 492 with a mixture containing 41.5 per cent total incombustible (30 per cent shale), with 1.8 per cent of gas in the ventilating current. In this test the flame extended 150 feet into the mixed-dust zone, and ignition might have been obtained if the percentage of gas had been a little higher.

PROPAGATION TESTS WITH 20-MESH COAL DUST.

Propagation was obtained in test 486 with a mixture containing 42.8 per cent incombustible (30 per cent shale), but was not obtained in test 493 with a mixture containing 50.1 per cent incombustible (40 per cent shale), there being no gas present in either test. At the time the latter test was run all surfaces of the mine were quite wet with condensation from the warm air. Propagation would probably have been obtained in this test if the mine had been dry. Propagation was not obtained in test 483 with a mixture containing 58.7 per cent incombustible (50 per cent shale). The flame extended to within 25 feet of the outer end of the zone, indicating that a slight decrease in incombustible material would have permitted complete propagation.

In tests 484 and 485 the coal dust used in the ignition zone was that from the No. 6 bed and not the Pittsburgh coal dust. Propagation was not obtained with mixtures containing 48.7 per cent and 66.4 per cent of incombustible (40 per cent shale and 60 per cent shale), respectively.

Propagation was obtained in test 487 with a mixture containing 58.2 per cent of incombustible (50 per cent shale), with 1.1 per cent gas in the ventilating current; also in test 489 with a mixture containing 66.7 per cent incombustible (60 per cent shale), with 2.2 per cent gas present. Propagation was not obtained in test 490 with a mixture containing 75.1 per cent incombustible (70 per cent shale) with 1.9 per cent gas present. However, the flame extended to within 50 feet of the outer end of the test zone, and a slight decrease in the combustible content or increase in the amount of gas used would permit propagation. In the test (No. 494) made with pulverized dust, propagation was obtained with a mixture containing 64.9 per cent incombustible (60 per cent shale).

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

The results of tests with 20-mesh coal dust indicated a dust of lower degree of sensitiveness than the dust previously described, but the last test with pulverized dust (test 494) showed that the finest sized dust with low moisture content had but little lower explosibility limit than for example Pittsburgh dust. The usual mine dust with higher moisture and ash content is fortunately less sensitive than Pittsburgh coal mine dust, and therefore does not require so much shale dust to obtain a comparatively sensitive mixture.

The amount of incombustible material necessary to mix with the dust from this coal to prevent ignition and propagation under various conditions is given in the following table:

Data showing amount of incombustible needed to prevent ignition or propagation in No. 6 coal tested.

[Calculated for 20-mesh coal, of which 20 per cent will pass 200-mesh.]

	Gas used.	Incombustible in mixture.	Shale used.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Nonignition.....	0	33	29
Do.....	2	45	35
Nonpropagation.....	0	59	50
Do.....	1	67	60
Do.....	2	78	78

These factors are based on the assumption that the coal dust present will contain at least 10 per cent moisture. For a lower moisture content a greater amount of total incombustible is necessary because a given percentage of shale dust is less effective than an equal percentage of moisture.

APPLICATION TO FIELD CONDITIONS.

The explosion tests have shown that with dust of the size found in the mine from which the sample was taken and with 1 per cent of gas in the ventilating current it is necessary to have 67 per cent incombustible (moisture plus ash) in the dust to prevent the propagation of an explosion already started. This is equivalent to a mixture containing about 60 per cent shale dust.

Examination of the analyses of the road dusts and rib dusts shows that, with one exception, they do not approach this content and therefore would propagate an explosion. To render these dusts nonexplosive when dry would require the addition of inert dust to that already in the mine in the following ratios:

250 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

Data showing additions of inert material needed to render inexplorable the road and rib dusts of an Illinois mine working the No. 6 bed.

Laboratory No. of sample.	Kind of dust.	Moisture plus ash (from analysis).	Desired percentage of incombustible.	Ratio of incombustible material to be added to dust already in the mine.
		<i>Per cent.</i>		
29748	Road dust	51.45	67	0.47
29749	do.	49.33	67	.54
29755	do.	48.15	67	.57
29758	do.	40.99	67	.79
29759	do.	65.43	67	.05
29760	do.	47.58	67	.59
29762	do.	31.91	67	1.06
29765	do.	21.75	67	1.37
29766	do.	49.78	67	.52
29767	do.	31.07	67	1.09
29769	Rib dust	39.32	67	.84
29751	do.	30.63	67	1.10
29756	do.	44.53	67	.68
29757	do.	25.18	67	1.27
29761	do.	31.52	67	1.07

Therefore in order that the mine dust be nonexplosive in the presence of 1 per cent gas the analysis of that portion of the dust passing through a 20-mesh screen should show at least 67 per cent of moisture plus ash, or, if dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washings in such a manner as to remove all fine dust from the timbers and ledges. If future samples of entry dusts from this Illinois mine should show materially higher proportions of fine dust (that passing through a 200-mesh sieve), the above-named percentage of incombustible desired (67) would have to be increased.

EXPLOSIBILITY TESTS OF TRINIDAD COKING COAL, COLORADO.

GENERAL CHARACTER OF THE EXPLOSION TESTS.

A 2½-ton sample of coking coal was obtained from a mine in the Trinidad region, Colorado. A series of six tests was made on 20-mesh and pulverized dusts prepared from this sample. The 20-mesh dust was prepared to approximate the dust found in the mine and the tests thereon were to determine if an explosion could be originated in or propagated through dust similar in size and composition to that found in the mine. Three of the six tests were standard ignition and three were standard propagation tests.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

This mine had been visited several times by engineers from the Bureau of Mines, and a few face samples, coal-dust samples, and mine-air samples had been collected.

The average analysis of three face samples taken at different times is as follows:

Results of average analysis of three face samples.

Moisture.....	per cent..	2.54
Volatile matter.....	do....	34.53
Fixed carbon.....	do....	50.16
Ash.....	do....	12.77
Moisture plus ash.....	do....	15.31
Ratio of volatile to total combustible.....		40.75

Three road-dust samples were collected, the analysis being as follows:

Results of screen tests and analysis of road-dust samples from a mine in the Trinidad district, Colorado, working a coking coal.

Laboratory No. of sample.	Analyses as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$.	Screen test; cumulative percentage through—	
	Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
12030	6.02	28.47	44.10	21.41	27.43	39.23		
29276	10.23	26.07	30.13	33.57	43.80	46.39	18.0	5.6
29275	4.80	31.16	37.42	26.62	21.42	45.43	38.5	23.0

These samples do not furnish a good basis from which to judge the size of the dust in the mine. It was thought probable that the dusts would average about 20 per cent through 200-mesh, and the experimental-mine tests were made with 20-mesh dust, 20 per cent of which would pass 200-mesh.

Ten mine-air samples were collected. A few analyses typical of the set are given herewith.

Data on mine-air samples from a mine in the Trinidad district, Colorado.

Laboratory No. of sample.	Ventilating conditions at point of sampling.	Methane in sample.
		<i>Per cent.</i>
9282	Sample collected near intake.....	0.19
9275	Sample gathered in secondary entry...	1.83
9281	Sample taken on main return.....	1.58
9278	do.....	1.03

The mine gave off methane in large quantities, and any system for rendering the dust inert would have to make allowance for this fact.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Three ignition tests were made, all with 20-mesh dust; two of these were without gas and one with 1.7 per cent gas present.

Two propagation tests were made with 20-mesh dust, one without gas and one with 1.6 per cent gas. One propagation test was made with pulverized dust, this being without gas.

The average analysis of the 20-mesh and pulverized Trinidad coal-dust just before mixing for the tests was as follows:

Results of average analysis of 20-mesh and 100-mesh Trinidad coal dust.

	20-mesh dust.	100-mesh dust.
Moisture.....per cent..	1.60	1.59
Volatile matter.....do....	36.67	36.19
Fixed carbon.....do....	50.58	51.06
Ash.....do....	11.15	11.16
	100.00	100.00
Ratio of volatile to total combustible.....	42.03	41.48

The average analysis of the shale dust used in these tests showed a moisture content of 1.23 per cent and a total incombustible content of 99.30 per cent.

The average sizing tests of the coal dust and shale dust are as follows:

Results of average sizing tests of the coal dust and shale dust.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
20-mesh coal dust.....	98.6	65.0	36.2	20.9
Pulverized coal dust.....			98.2	92.4
20-mesh shale dust.....	95.6	78.4	53.6	40.5
Pulverized shale dust.....			99.8	97.8

The average sizing test on the pulverized Pittsburgh coal dust used in the ignition zone in the propagation tests showed 99.8 per cent through 100-mesh and 88.2 per cent through 200-mesh. The average analysis of this coal dust gave a moisture plus ash content of 5.86 per cent and a ratio of volatile combustible to total combustible of 39.42 per cent.

The principal data in connection with the explosion tests on this coal are presented in Table 27.

TABLE 27.—Results of standard tests of coal dust from Trinidad coking coal, Colorado.

[Originating cause: Standard blown-out shot from cannon at station E 1200. Size of coal dust used, 20-mesh, 20 per cent of which would pass 200-mesh, and pulverized. Size of pit-shale dust used, 20-mesh and pulverized. In the ignition tests the rate of mixed-dust loading in the first 60 feet was twice that used in the rest of the zone, and given in the table. The mixed-dust zone extended from stations E 1200 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1200 to E 1250. The mixed-dust zone extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale in this mixture.	Mixed dust.			Records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
				Calculated.	Rate of loading.	Total loading.		Sta- tion 1150.	Sta- tion 950.	Fol at station locity. 1250.	Fol at Ve- station locity. 1150.	Fol at Ve- station locity. 1050.	Fol at Ve- station locity. 950.	Fol at station locity. 1150.	Fol at Ve- station locity. 1050.			Fol at Ve- station locity. 950.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
470	1918. Mar. 28	20-mesh	70:30	Per cent. 39.2	Lbs. per ft. 1.43	Lbs. 1,071	Per cent. 0.0	Lbs. per sq. in. 2	Lbs. per sq. in. 2	Sec. onds. 0.823	Feet per sec. 73	Sec. onds. 1.866	Feet per sec. 115	Sec. onds. 3.307	Feet per sec. 92	Sec. onds. 4.399	Feet per sec. 3.098	Feet.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
490	Mar. 28	do	60:40	47.8	1.67	1,250	.0	1	1	.706									Feet.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							

PROPAGATION TESTS.

1918. 472 Apr. 1	20-mesh	50:50	56.3	2.00	1,300	0.0 {Air course.	4	5	0.312	144	1.004 1.034	103 177	1.968 1.569	106 633	2.915 1.767	{(c) 50 100	Propagation obtained.
473 Apr. 3	do....	25:75	78.1	4.00	2,600	1.6 {Air course.	1	1	.270	22	4.866	.....	.....	.....	.....	.....	Propagation not obtained.
474 Apr. 4	Pulver- ized.	25:75	78.2	4.00	2,600	.0 {Air course.	3	3	.183	134	.927 1.197	 242	 1.611	72 342	3.708 1.903	{(c)	Propagation obtained.

^a Flame extended through zones.^b Flame velocity and pressure curves of this test are shown in figure 64.

DISCUSSION OF RESULTS.

IGNITION TESTS.

Ignition was obtained in test 470 with a mixture of 20-mesh coal dust and shale dust containing 39.2 per cent total incombustible (30 per cent shale), but was not obtained in test 469 with a mixture containing 47.8 per cent total incombustible (40 per cent shale), both tests being without gas. Ignition was obtained in test 471 with a mixture of 20-mesh coal dust and shale dust containing 56.5 per cent total incombustible (50 per cent shale), there being 1.7 per cent gas in the ventilating current. The pressures and flame velocities obtained in this test indicate that the dust would require a total incombustible content of about 65 per cent (60 per cent shale) to prevent ignition in the presence of two per cent of gas.

PROPAGATION TESTS.

Propagation was obtained in test 472 with a mixture of 20-mesh coal dust and shale dust containing 56.3 per cent total incombustible (50 per cent shale), no gas being used, but not in test 473 with a mixture having a total incombustible content of 78.1 per cent (75 per cent shale), there being 1.6 per cent of gas in the ventilating current. In this latter test the flame extended only 100 feet into the mixed dust, and this mixture probably would not propagate an explosion with 2 per cent of gas in the ventilating current. Also a reasonable conjecture would be to consider 80 per cent total incombustible as a safe mixture with 2 per cent of gas present. Propagation was obtained in test 474 with a mixture of pulverized coal dust containing 78.2 per cent total incombustible (75 per cent shale), there being no gas in the ventilating current.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

The last test (474) shows that the coal dust of this mine, when fine, has a high explosive limit. It is regrettable in this case, as in others, that it was not feasible to send a larger sample of coal, so that more determinations of limits could be made, also that more road dust and rib samples had not been obtained, to give more thorough knowledge of the mine dust conditions, in making recommendations.

The amount of shale dust or total incombustible material necessary to prevent ignition and propagation in mixtures of 20-mesh coal dust of which 20 per cent would pass 200 mesh from this seam is shown in the following table. The total incombustible included the moisture and ash of the coal dust as well as the admixed shale dust.

Data showing incombustible needed to make nonexplosive the coal dust from a mine in the Trinidad district, Colorado, the dust being 20-mesh of which 20 per cent will pass 200-mesh.

	Gas.	Total incombustible.	Shale dust.
	Per cent.	Per cent.	Per cent.
Nonignition.....	0	48	40
Do.....	2	65	60
Nonpropagation.....	0	65	60
Do.....	2	80	77

APPLICATION TO FIELD CONDITIONS.

Reference to the analyses for the three road-dust samples shows that the maximum moisture and ash content was 43.80 per cent; consequently all three would ignite and would propagate an explosion, probably with great violence. Because of the presence of gas in this mine it would be necessary to have a total incombustible content of 80 per cent to prevent propagation. To render these road dusts nonexplosive when dry would require the addition of an inert dust to that already in the mine in the following ratios:

Additions of inert dust needed to make nonexplosive the road dusts of a mine working a bed of coking coal, Trinidad district.

Laboratory No. of sample.	Moisture and ash (from analysis).	Desired percentage of incombustible.	Ratio of incombustible material to be added to dust already in mine.
	Per cent.		
12030	27.43	80	3.12
29276	43.80	80	1.81
29275	31.42	80	2.43

Therefore, in order that the mine dust be nonexplosive in the presence of gas up to 2 per cent the analysis of that portion of the dust passing through a 20-mesh screen should show at least 80 per cent of ash plus moisture, or, if dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washing in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF DUST OF A SUBBITUMINOUS COAL FROM WYOMING.

GENERAL CHARACTER OF THE EXPLOSION TESTS.

A series of five explosion tests was made of 20-mesh and pulverized dusts prepared from a 2½-ton sample of subbituminous coal obtained from a mine in Wyoming. The object of this series was to determine the percentages of shale dust necessary to prevent ignition and to prevent propagation of an explosion under test conditions, both with and without gas in the air current. One set of tests was made with dust crushed to the standard size nearest to the size of dust found in

the mine from which the coal was taken. A second set was made with pulverized dust to obtain the maximum explosibility of the coal in order to make comparison with coals from other seams.

CONDITIONS IN MINE WHERE SAMPLE WAS TAKEN.

Examination was made of the conditions in the mine from which this sample was obtained, in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane, so that the tests at the experimental mine might approximate the mine conditions.

Five standard face samples of the coal were obtained. Results of the analyses of these samples were as follows:

Results of analyses of face samples of subbituminous coal from a mine in Wyoming.

Laboratory No. of sample.	Coal as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
24447	16.65	34.17	45.83	3.35	20.00	42.71
24448	17.54	33.26	44.76	4.44	21.98	42.62
24449	15.92	33.04	46.89	4.45	20.37	41.19
24450	16.60	33.37	46.48	3.55	20.15	41.78
24451	17.64	33.75	44.19	4.42	22.06	42.62

The analysis of a composite of the five samples is as follows:

Results of analysis of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....per cent..	18.94
Volatile matter.....do....	33.06
Fixed carbon.....do.....	45.96
Ash.....do.....	4.04
Moisture plus ash.....do....	20.98
Ratio of volatile to total combustible.....do.....	41.83

Ultimate analysis:

Hydrogen.....per cent..	5.55
Carbon.....do.....	58.60
Nitrogen.....do.....	1.29
Oxygen.....do.....	26.64
Sulphur.....do.....	.65
Ash.....do.....	7.27

Nine samples of road dust and one of rib dust were taken in the mine. The analysis and sizing test of these samples are given in the following table:

Results of analyses and sizing tests of road and rib dusts from a Wyoming mine working a subbituminous bed.

Laboratory No. of sample.	Kind of dust.	Analyses as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$	Screen test; cumulative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
24455....	Road dust.	17.24	30.22	42.99	9.55	26.79	41.28	.....	.....
24456....	do.....	15.67	25.64	30.52	28.17	43.84	45.66	25.5	16.0
24457....	do.....	17.61	24.57	29.99	27.83	45.44	45.87	28.3	13.3
24458....	do.....	16.30	21.64	25.34	36.72	53.02	46.06	31.8	18.4
24459....	do.....	15.64	23.14	24.02	37.20	52.84	49.07	26.4	14.4
24460....	do.....	16.85	27.57	33.80	21.78	38.63	44.92	32.3	20.6
24461....	do.....	16.81	27.30	27.98	27.91	44.72	49.38	32.7	18.7
24462....	do.....	22.57	29.71	38.58	9.14	31.71	43.51	30.8	20.4
24527....	do.....	17.68	30.68	40.25	11.59	29.17	43.17	35.1	21.1
24528....	Rib dust..	16.63	33.67	36.74	12.96	29.59	47.82	.....	.....

The content of moisture plus ash in the road dust samples ranged from 26.79 to 53.02 per cent, the average being 40.68 per cent. The proportion of 200-mesh dust in the samples varied from 14.4 per cent to 20.6 per cent, the average being 18 per cent. It will be noted that four of the samples have in the neighborhood of 30 per cent, or less, of ash plus moisture. The coal dust for the tests in the experimental mine was prepared so that about 20 per cent would pass 200-mesh.

A number of mine-air samples were taken and analyses of these showed no methane present.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Two ignition tests were made with 20-mesh coal dust, 20 per cent of which passed through a 200-mesh screen, and one was made with pulverized dust. All three ignition tests were made without gas.

Two propagation tests were made with 20-mesh coal dust, 20 per cent of which passed through a 200-mesh sieve, both tests being made without gas present.

The average results of the analyses and screen tests of the Wyoming coal dust as prepared for the tests were as follows:

Average composition and fineness of 20-mesh and of pulverized coal dust used.

Proximate analysis:	20-mesh dust.	Pulverized dust.
Moisture.....per cent..	18.84	11.96
Volatile matter.....do....	32.33	36.55
Fixed carbon.....do....	45.20	47.05
Ash.....do....	3.63	4.44
Ratio of volatile to total combustible.....	41.70	43.72
Screen test; cumulative percentage through—		
100-mesh screen.....	37.9	98.2
200-mesh screen.....	21.3	64.8

Pit-shale dust was used in the tests, the content of incombustible material therein being over 99 per cent. The 20-mesh shale dust mixed with the 20-mesh coal dust averaged about 30 per cent through 200-mesh.

Table 28 herewith presents the chief data in connection with the explosion tests of this coal:

TABLE 28.—Results of standard tests of coal dust from a subbituminous bed, Wyoming.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used, 20-mesh, of which 20 per cent would pass 20-mesh, and pulverized. Size of pit-shale dust used, 20-mesh and pulverized. In the ignition tests, the mixed-dust zones extended from stations E 1340 to E 960, 380 feet, and from stations E 1260 to A 960, 330 feet; total length, 700 feet. In the propagation tests, the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1260. The mixed-dust zones extended from stations E 1260 to E 960, 300 feet, and from stations E 1260 to A 960, 360 feet; total length, 660 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.				Length of flame in mixed-dust zone.	Remarks.
				Mol.-ture concen- trant.	Calcu- lated incom- busti- ble.	Rate of load- ing.	Total load- ing.	Sta- tion 1150.	Sta- tion 960.	Fall at station locality. 1260.	Fall at station locality. 1150.	Fall at station locality. 1060.	Fall at station locality. 960.		
314	1916. Apr. 24	20-mesh	(e)	Per cent. 19.0	Per cent. 22.5	Lbs. per ft. 2.00	Lbs. 1,400	Lbs. per sq. in. 12	Lbs. per sq. in. 13	Sec. onds. 0.928	Sec. onds. 1.883	Sec. onds. 1.775	Sec. onds. 1.124	Fet. 2,642	Ignition obtained.
315	Apr. 26	do....	80:20	15.2	38.1	2.50	1,750	1	1	2.225	91	3.328	2.950	175 } 200 }	Ignition not obtained.
319	May 3	Pulver- ized.	50:50	6.9	58.2	2.00	1,400	14	13	.690	147	1.371	1.309	194 } 171 }	Ignition obtained.

PROPAGATION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Per cent.	Lbs. per ft.	Rate of load- ing.	Total load- ing.	Entry.... {Air course.	4	0.300	183	0.818	.840	1.250	148 } 556 }	2.173 } 1.430 }	Propagation obtained.
321	1916. May 8	20-mesh	70:30	14.3	46.2	1.43	929	{Entry.... {Air course.	1	5	.....	.....	244	.....	187 } 389 }	2.183 } 1.628 }	Do.
322	May 10	do....	60:40	10.9	52.9	1.67	1,063	{Entry.... {Air course.	4	5	.420	.987	.....	1.371	.....	.....	Do.

a All coal.

b Flame extended through zones.

DISCUSSION OF RESULTS.

IGNITION TESTS.

Ignition was obtained in test 314 with pure Wyoming coal dust of 20-mesh size—20 per cent of which would pass 200-mesh—containing 19.0 per cent moisture, but was not obtained in test 315 through a mixture of 80 per cent 20-mesh coal dust and 20 per cent 20-mesh shale dust, the mixed dust containing 15.2 per cent moisture.

Ignition was obtained in test 319 with a mixture of 50 per cent pulverized coal dust and 50 per cent pulverized shale dust, the mixed dust containing only 6.9 per cent moisture.

PROPAGATION TESTS.

Propagation was obtained in test 321 with a mixture of 70 per cent 20-mesh coal dust and 30 per cent 20-mesh shale dust, and was also obtained in test 322 with a mixture of 60 per cent 20-mesh coal dust and 40 per cent 20-mesh shale dust. There was very little difference in the pressures and velocities of the two tests. Tests with other coals of somewhat similar composition have led to the supposition that a mixture of 50 per cent 20-mesh coal dust and 50 per cent 20-mesh shale dust would in all probability fail to propagate, provided the coal contained the normal amount of moisture.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

A comparison of test 315 with test 319 shows strikingly the contrast of the relative nonexplosibility of subbituminous or lignitic dust of natural mine sizing and the high explosibility of pulverized subbituminous or "black lignite" dust.

The explosion tests of this coal showed that to prevent ignition under the test conditions in the absence of gas it was necessary to have 20 per cent of shale dust in the mixture, the total content of incombustible material in the mixture being about 38 per cent.

To prevent propagation would require the presence of at least 50 per cent shale dust, the total incombustible material of the mixture being about 60 per cent.

These figures apply to 20-mesh coal dust of which 20 per cent would pass 200-mesh, the coal dust containing 19 per cent of moisture.

APPLICATION TO FIELD CONDITIONS.

Examination of the road-dust samples shows that the average percentage of 200-mesh dust is 18.1. The single sample of rib dust contained nearly 30 per cent of dust that would pass 200-mesh. It is probable that a general average of a large number of road and rib dust samples would show more than 20 per cent of dust passing 200-mesh. In view of this fact and the uncertainty as to the exact mixture which would prevent propagation it would be better to place

the limit of propagation in the absence of gas as 65 per cent incombustible. As no gas was found in this mine,^{44a} no additional allowance is necessary; although that condition might not hold in future.

It will be observed that none of the road-dust samples contain 65 per cent of moisture plus ash; consequently all of them would propagate an explosion.

The following table gives the ratio of incombustible dust to be added to the dust already in the mine to obtain the desired 65 per cent of incombustible material in the resulting mixture:

Data showing additions of incombustible necessary to render inexplosible the mine dusts of a subbituminous coal mine, Wyoming.

Laboratory No. of sample.	Kind of dust.	Moisture and ash (by analysis).	Desired percentage of incombustible.	Ratio of incombustible to be added to get desired percentage.
		<i>Per cent.</i>		
24455	Road dust.	26.79	65	1.09
24456	do.....	43.84	65	.60
24457	do.....	45.44	65	.56
24458	do.....	53.02	65	.34
24459	do.....	52.84	65	.35
24460	do.....	28.63	65	.75
24461	do.....	44.72	65	.53
24462	do.....	31.71	65	.95
24527	do.....	29.17	65	1.02
24526	Rib dust..	29.59	65	1.01

Therefore in order that the mine dust be nonexplosive in the absence of gas the analyses of that portion of the dust passing through a 20-mesh screen should show about 65 per cent of moisture plus ash. The amount of moisture in the mixture should be at least 19 per cent of the amount of coal dust. If dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washings in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE KEOKEE BED, EASTERN KENTUCKY.

GENERAL DESCRIPTION OF TESTS.

A series of fourteen explosion tests was made on coal dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine in eastern Kentucky working the Keokee seam. The object of this series was to determine the percentages of shale necessary to prevent ignition and to prevent propagation of an explosion under standard test conditions, both with and without gas in the ventilating current. One set of tests was made with dust crushed to the standard size nearest to the size of dust found in the mine from which the coal

^{44a} Workings in an adjoining mine give off fire damp.

was taken. A second set was made with pulverized dust to obtain the maximum explosibility of the coal in order to make comparison with coals from other seams.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Prior to the time of taking the large sample the mine had been examined, and samples of coal, road dust, rib dust, and mine air were collected.

The analyses of the four face samples of coal collected were as follows:

Results of analyses of four face samples of the Keokee coal.

Laboratory No. of sample.	Proximate analysis (coal as received).				Ratio $\frac{V}{V+FC}$	Moisture plus ash.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>
24834	2.64	36.83	58.45	2.06	38.68	4.72
24835	2.59	37.25	58.37	1.79	38.96	4.38
24836	2.74	36.99	58.12	2.15	38.98	4.59
24837	2.80	37.80	56.74	2.66	40.00	5.46
Av..	2.69	37.22	57.92	2.17	39.15	4.86

The ultimate analysis of a composite sample was as follows:

Results of ultimate analysis of composite sample.

	Per cent.
Hydrogen.....	5.56
Carbon.....	80.94
Nitrogen.....	1.52
Oxygen.....	9.11
Sulphur.....	.52
Ash.....	2.35
	100.00

Three samples of road dust and three of rib dust were collected. The analyses and screen tests of these samples are as follows:

Results of analyses and screen tests of road and rib dusts from a coal mine in eastern Kentucky working the Keokee bed.

Laboratory No. of sample.	Kind of dust.	Analyses as received				Moisture plus ash.	Screen test; cumulative percentage of 20-mesh dust through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.		100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
24839	Road dust	2.69	20.28	32.32	44.71	47.40	28.2	18.3
24840	do.....	2.28	25.40	43.24	29.08	31.36	32.6	21.0
24841	do.....	3.49	21.15	34.31	41.05	44.54	42.1	29.8
24842	Rib dust	2.76	29.94	56.69	10.61	13.37	.....	.....
24843	do.....	3.56	24.92	45.41	26.11	29.67	57.2	45.6
24844	do.....	3.25	27.22	49.03	20.50	23.75	43.4	31.4

The content of ash plus moisture in the road-dust samples ranged from 31.36 to 47.40 per cent; the percentage of dust passing 200-mesh ranged from 18.3 to 29.8.

The content of moisture plus ash in the rib dust samples ranged from 13.37 to 29.67 per cent; the percentage of dust passing 200 mesh ranged from 31.4 to 45.6.

A consideration of the results of the sizing tests on these samples led to the adoption of 20-mesh dust, 40 per cent of which would pass 200-mesh, as the size to be used in the tests at the experimental mine.

A number of samples of mine air were taken, of which the following are typical:

Typical analyses of mine-air samples from a mine in Kentucky working the Keokee bed.

Lab- oratory No. of sample.	Condition of air and place of sampling.	Methane in sample.
7366	Sample collected in secondary split....	<i>Per cent.</i> 0.10
7367	do.....	.08
7368	do.....	.22
7375	do.....	.06
7369	Sample collected in main return.....	.07
7370	do.....	.10

The samples show very little methane, the highest content found being less than 0.25 per cent, whereas the main-return air showed not more than 0.1 per cent.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Eight tests were made with 20-mesh coal dust, 40 per cent of which would pass through 200-mesh, three being ignition and five being propagation tests. Two of the ignition and three of the propagation tests were made with gas present. Six tests were made with pulverized dust, three being ignition and three propagation. One propagation and two ignition tests were made with gas. The results of these tests are shown in Table 29.

The average analysis of the pulverized and of the coarse (20-mesh) Kentucky coal dust used in the tests was as follows:

	Pulver- ized dust.	20-mesh dust.
Moisture.....per cent..	1.56	2.13
Volatile matter.....do....	37.41	37.40
Fixed carbon.....do....	57.23	56.89
Ash.....do....	3.80	3.58
	100.00	100.00
Ratio of volatile to total combustible.....	39.53	39.66

The average analysis of the pit-shale dust used showed: Moisture, 1.25 per cent; other incombustible, 98.19 per cent; total incombustible, 99.44 per cent.

The average analysis of the Pittsburgh coal dust used in the 50-foot ignition zones of the propagation tests was as follows:

Results of average analysis of Pittsburgh coal dust used.

Moisture.....	per cent..	1.69
Volatile matter.....	do....	38.35
Fixed carbon.....	do....	55.85
Ash.....	do....	4.11
		100.00
Ratio of volatile to total combustible.....		40.71

The average sizing tests of the coal dust and shale dust used in the tests were as follows:

Results of average sizing tests of coal dust and shale dust used.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Pulverized coal dust.....			98.3	77.1
20-mesh coal dust.....	97.7	77.6	57.8	40.0
Pulverized shale dust.....			98.4	90.5
20-mesh shale dust.....	93.1	72.8	48.5	36.9
Pittsburgh coal dust.....			98.4	77.6

The principal data in connection with the explosion tests are presented in Table 29.

TABLE 29.—Results of standard tests of coal dust from the Keokee bed, eastern Kentucky.

[Originating cause: Standard blow-out shot from cannon at station E 1300. Size of coal dust used: 20-mesh, 40 per cent of which would pass 200-mesh, and pulverized. Size of pit-shale dust used: 20-mesh and pulverized. In the ignition tests the rate of mixed-dust loading in the first 30 feet was twice that used in the rest of the zone and given in the table. The mixed-dust zone extended from stations E 1300 to E 960, 340 feet, and from stations E 1250 to A 960, 330 feet, total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 960, 300 feet, and from stations E 1250 to A 960, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed dust zone.	Remarks.
				Calculated in combustible.	Rate of loading.	Total loading.		Station 1150.	Station 960.	Foil at station 1250.	Ve-locity, 1250.	Foil at station 1150.	Ve-locity, 1150.	Foil at station 1050.	Ve-locity, 1050.	Foil at station 950.	
401	1917. Mar. 26	20-mesh	50:50	Per cent. 83.1	Lbs. per ft. 2.00	Lbs. 1,600	Nat-ural gas used. 0.0	Lbs. per sq. ft. 2	Lbs. per sq. ft. 2	Sec-onds. 1.035	Feet per sec. 99	Sec-onds. 2.060	Feet per sec. 73	Sec-onds. 3.418	Feet per sec. 25	Sec-onds. 7.488	Ignition obtained.
402	Mar. 27	do.	40:60	62.1	2.50	1,875	1.05	1	1	.798							Ignition not obtained.
412	Apr. 11	do.	30:70	71.7	3.33	2,600	2.03	1	2	1.012	67	2.504	39	5.085			Do.
413	Apr. 12	Pulver-ized.	40:60	62.2	2.50	1,875	.0	1	1	1.388	45	2.562					Do.
403	Mar. 29	do.	30:70	71.4	3.33	2,600	1.90	9	10	2.257	291	2.401					Ignition obtained.
410	Apr. 10	do.	25:75	76.5	4.00	3,000	1.70	1	1	2.793							Ignition not obtained.

PROPAGATION TESTS.

1917.	20-mesh	40:80	62.3	2.50	1,625	0.0	Entry..... { Air course.	4	6	0.242	171	0.826	137	1,555	224	1,982	(e)	Propagation obtained.
406	Apr. 3	40:80	62.3	2.50	1,625	0.0	Entry..... { Air course.	4	6	0.242	171	0.826	137	1,555	224	1,982	(e)	Propagation obtained.
405	Apr. 2	30:70	71.6	3.33	2,167	.0	Entry..... { Air course.	1	1	.384	48	2,453	296	1,369	430	1,561	100 200	Propagation not obtained.
4144	Apr. 13	30:70	71.7	3.33	2,167	.84	Entry..... { Air course.	2	2	.249	156	.902	75	2,224	78	3,524	(e)	Propagation obtained.
408	Apr. 6	25:75	76.5	4.00	2,600	1.72	Entry..... { Air course.	5	6	.259	243	.669	181	1,220	120	1,996	(e)	Do.
407	Apr. 5	20:80	81.1	5.00	3,250	1.89	Entry..... { Air course.	1	1	.274	48	2,340	23	6,888	.....	.....	150 225	Propagation not obtained.
409	Apr. 9	{ Pulver. Ised. } 30:70	71.4	3.33	2,167	.0	Entry..... { Air course.	7	9	.....	.....	.918	181	1,470	435	1,700	(e)	Propagation obtained.
411	Apr. 10	25:75	76.5	4.00	2,600	.0	Entry..... { Air course.	1	2	.430	107	1,362	36	4,142	610	1,624	150 250	Propagation not obtained.
415	Apr. 16	20:80	81.3	5.00	3,250	1.03	Entry..... { Air course.	1	1	.323	70	1,769	92	2,830	.....	.....	125 250	Do.

Flame velocity and pressure curves of this test are shown in figure 69.

Flame extended through zone.

DISCUSSION OF RESULTS.

IGNITION TESTS WITH 20-MESH DUST.

Three tests of this class were made, one without gas in the ventilating current and two with gas present. A very weak ignition was obtained in test 401 with a mixture of 50 per cent coal dust and 50 per cent shale dust, without gas, but ignition was not obtained (test 402) with 10 per cent less coal dust and more shale dust, even when there was 1.05 per cent gas in the ventilating current. Ignition was not obtained (test 412) with a mixture of 30 per cent coal dust and 70 per cent shale dust, with 2 per cent gas in the ventilating current.

PROPAGATION TESTS WITH 20-MESH DUST.

Five tests of this class were made, two without gas and three with gas present. Propagation was obtained (test 406) with 40 per cent coal dust and 60 per cent shale dust when no gas was used, but was not obtained (test 405) with 30 per cent coal dust and 70 per cent shale dust. This latter mixture, however, gave propagation (test 414) with 0.8 per cent gas in the ventilating current.

Propagation was also obtained (test 408) with a mixture of 25 per cent coal dust and 75 per cent shale dust, with 1.75 per cent gas present, but was not obtained (test 407) with a mixture of 20 per cent coal dust and 80 per cent shale dust, with 1.9 per cent of gas in the ventilating current.

It will be noted that a higher percentage of shale is needed to prevent propagation than ignition; that is, more incombustible material is required to stop an explosion once started than merely to prevent an explosion from starting.

IGNITION TESTS WITH PULVERIZED DUSTS.

Three tests of this class were made, one without gas and two with gas present. Ignition was not obtained (test 413) with a mixture of 40 per cent pulverized coal dust and 60 per cent shale dust, with no gas present, although there was considerable extension of flame, indicating that the mixture was close to the limit. A mixture of 50 per cent of pulverized coal dust and 50 per cent shale dust would give ignition, however, as these proportions gave ignition with 20-mesh coal dust. Strong ignition was obtained (test 403) with 30 per cent coal dust and 70 per cent shale dust, with 1.9 per cent gas in the air current, but was not obtained (test 410) with a mixture of 25 per cent coal dust and 75 per cent shale dust, with 1.8 per cent gas in the air current, there being practically no extension of flame in this latter test.

PROPAGATION TESTS WITH PULVERIZED DUST.

Three tests of this class were run, two being without gas and one with gas present. Strong propagation was obtained (test 409) with 30 per cent coal dust and 70 per cent shale dust, without gas, but was not obtained (test 411) with 25 per cent coal dust and 75 per cent shale dust. Propagation was not obtained (test 415) with 20 per cent coal dust and 80 per cent shale dust, with 1 per cent gas in the air current, but the extension of flame in this test indicates that propagation would be obtained with a slight increase in the gas content of the air.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

The following table gives the percentages of shale dust or incombustible material which are required to be mixed with this coal to prevent ignition and to prevent propagation under the test conditions at the experimental mine.

Data showing additions of inert dust needed to render harmless the coal dust in a mine working the Keokee bed.

	Gas present.	20-mesh dust, of which 40 per cent would pass 200-mesh.		Pulverized dust.	
		Incombustible.	Shale dust.	Incombustible.	Shale dust.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nonignition.....	0	62	60	62	60
Do.....	1	62	60	72	70
Do.....	2	72	70	76	75
Nonpropagation.....	0	72	70	76	75
Do.....	1	76	75	76	75
Do.....	2	81	80	.....	.....

APPLICATION TO FIELD CONDITIONS.

The explosion tests show that dust from the mine where this sample was taken must have a total incombustible content of 72 per cent to prevent propagation under test conditions, the dust being of the same size as the samples taken from the mine. If there is 1 per cent of gas present, 76 per cent incombustible will be needed to prevent propagation. However, as this mine makes little gas, 74 per cent incombustible can be considered as a safe figure for the road and rib dusts.

The following table gives the ratio of incombustible necessary to add to each sample of road dust or of rib dust to raise the incombustible to the required 74 per cent.

Data showing additions of incombustible needed to make the mine dust nonexplosive.

Laboratory No. of sample.	Kind of dust.	Incombustible desired.	Moisture and ash content of sample.	Ratio of incombustible to be added.
		<i>Per cent.</i>	<i>Per cent.</i>	
24839	Road dust	74	47.40	1.02
24840	...do.....	74	31.36	1.64
24841	...do.....	74	44.54	1.13
24842	Rib dust..	74	13.37	2.33
24843	...do.....	74	29.67	1.70
24844	...do.....	74	23.75	1.93

The total amount of rock dust that would be necessary to accomplish this result would be materially reduced if the entries were cleaned before the application. The moisture and ash of the coal are counted as a part of the incombustible material.

If dependence is placed on wetting for rendering coal dust inert, the mine should be kept thoroughly wetted by frequent washings in such a manner as to remove all the fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE UPPER FREEPORT OR E BED, INDIANA COUNTY, PA.

DESCRIPTION OF TESTS, AND RESULTS.

Eleven tests were made on a sample of run-of-mine coal obtained from a mine working the Upper Freeport seam in Indiana County, Pennsylvania. Tests on this coal were made prior to the development of the methods of field investigation, and consequently no samples of the dust were taken in the mine from which the coal was obtained. All the tests were made with pulverized coal dust. The two standard classes of tests, ignition and propagation, were made. Seven ignition tests were made with pulverized dust, two without gas and five with gas in the ventilating current. Four propagation tests were made with pulverized dust, two without gas and two with gas in the ventilating current.

The average analysis of samples of the Upper Freeport coal dust was as follows:

Results of average analyses of the Upper Freeport coal dust.

[Analysis on basis of coal as received.]

Average proximate analysis:

Moisture.....per cent..	1.02
Volatile matter.....do....	28.49
Fixed carbon.....do....	59.27
Ash.....do....	11.22
Moisture plus ash.....do....	12.24
Ratio of volatile to total com- bustible.....do....	32.46

Average ultimate analysis:

Hydrogen.....per cent..	4.79
Carbon.....do....	78.24
Nitrogen.....do....	1.45
Oxygen.....do....	4.33
Sulphur.....do....	2.57
Ash.....do....	10.62

The average of the screen tests of the coal dust used showed 100 per cent through 100-mesh; 96 per cent through 200-mesh (screen A); and 93 per cent through 240-mesh.

The shale used to mix with the coal in these tests was pit shale containing over 99 per cent incombustible material, the average sizing test being as follows: 100 per cent through 100-mesh; 97 per cent through 200-mesh (screen A); and 94 per cent through 240-mesh.

The main data in connection with the explosion tests are presented in Table 30.

TABLE 30.—Results of standard tests of coal dust from the Upper Freeport or E bed, Indiana County, Pa.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used: Pulverized. Size of pit-shale dust used: Pulverized. In the ignition tests the mixed-dust zones extended from stations E 1300 to E 950, 350 feet; and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Mixed dust.				Natural gas used.	Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.	
		Ratio of coal dust to shale dust in mixture.	Calculated incombustible.	Rate of loading.	Total loading.			Station 1150.	Station 950.	Fall at station 1250.	Velocity.	Fall at station 1150.	Velocity.	Fall at station 1050.	Velocity.			Fall at station 950.
211	1915. May 6	50 : 50	55.8	4.00	2,800	Per ct. 0.0	{Entry..... {Air course.....	Lbs. per sq. ft. 12	Lbs. per sq. ft. 11	Sec. on ds. 1.007	96	Sec. on ds. 2.172	92	Sec. on ds. 2.896	667	Sec. on ds. 2.736	Fest. { (e) 2.551	Ignition obtained.
212	May 7	40 : 60	65.0	5.00	3,500	.0	{Entry..... {Air course.....	0	0	.....	.....	2.177	355	2.459	1,057	2.551		
213	do.....	40 : 60	65.0	5.00	3,500	.51	{Entry..... {Air course.....	2	3	1.167	46	3.350	81	4.592	323	4.793	50	Ignition not obtained.
216	May 12	30 : 70	72.6	5.00	3,500	.99	{Entry..... {Air course.....	0	0	0	.....	3.450	179	4.069	323	4.340		
217	do.....	30 : 70	72.6	5.00	3,500	2.13	{Entry..... {Air course.....	0	0	0	.....	.....	.....	.....	.....	.....	50	Do.
218	do.....	30 : 70	72.6	5.00	3,500	2.72	{Entry..... {Air course.....	15	15	1.260	190	1.785	.....	1.753	976	1.960		
219	May 17	20 : 80	82.5	5.00	3,500	3.15	{Entry..... {Air course.....	17	17	.....	.....	1.573	636	.....	1,468	1.790	50	Ignition obtained.
							{Entry..... {Air course.....	0	0	1.877	.....	.....	.....	.....	.....	.....		

PROPAGATION TESTS.

	1916.																
215	May 11	40 : 60	86.1	5.00	3, 250	0.0	{Entry..... Air course.	5 10	5 6	0.448	172	1, 028	155	1, 672 1, 350	455 704	1, 893 1, 462	Propagation obtained.
214	May 10	30 : 70	72.7	5.00	3, 250	.0	{Entry..... Air course.	1 1	1 1	.069	50	2, 645 1, 856	.....	.....	.....	.....	Propagation not ob- tained.
221	May 19	30 : 70	72.6	5.00	3, 250	.84	{Entry..... Air course.	2 2	 1	.004	15	7, 198	.....	.....	.....	.....	Do. Do.
220	May 17	20 : 80	82.5	5.00	3, 250	2.04	{Entry..... Air course.	1 2	1 1	.741	55	2, 567	.....	.....	.....	.....	Do. Do.

Flame extended through zones.

DISCUSSION OF RESULTS.

IGNITION TESTS.

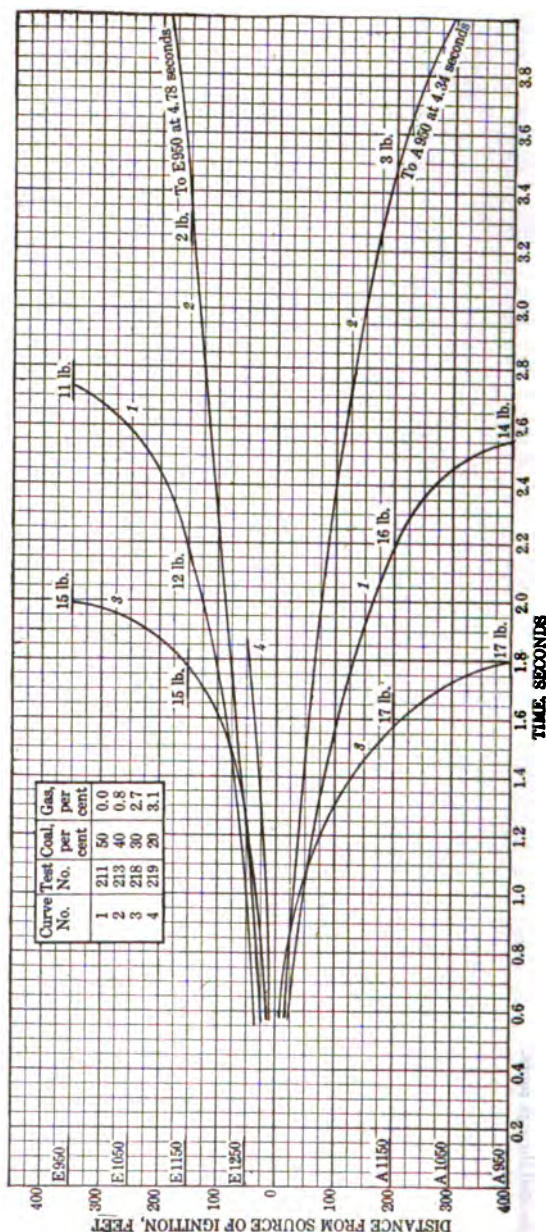


FIGURE 36.—Flame-velocity curves for standard ignition tests of mixtures of Upper Freeport coal dust and pit-shale dust. Figure in *italics* denotes number of curve; figures in *roman* denote maximum pressure developed at that point in pounds per square inch.

Ignition was obtained in test 211 with a mixture of 50 per cent coal dust and 50 per cent shale dust, but was not obtained in test 212 with a mixture of 40 per cent coal dust and 60 per cent shale dust.

Ignition was obtained in test 213 with a mixture similar to that used in test 212, with 0.8 per cent gas in the air current, but was not obtained in test 216 with a mixture of 30 per cent coal dust and 70 per cent shale dust, with 1 per cent gas present, the flame extending only 50 feet from the cannon. The mixture of 30 per cent coal dust and 70 per cent shale dust was used again in test 217, with 2.1 per cent gas in the air current, and failed to give ignition.

In test 218 the

mixture was again used, with 2.7 per cent of gas, and strong ignition resulted. Pressures of 15 to 17 pounds were measured at the stations in the explosion zone. The velocity of the explosion was greater than in either of the two previous tests in which ignition was obtained.

In test 219 ignition was not obtained with a mixture of 20 per cent coal dust and 80 per cent shale dust, with 3.1 per cent of gas in the air current.

Figure 36 shows the flame-velocity curves for tests 211, 213, and 218, in which ignition was obtained. It will be observed that the velocities in test 213 were less than those in test 211, test 213 having 10 per cent more shale in the mixture and 0.8 per cent gas in the ventilating current. Again, increasing the shale dust 10 per cent and raising the gas from 0.8 to 2.7 per cent (in test 218) gave an explosion more violent than either of the preceding explosions, showing that the additional gas present more than offset the additional shale dust.

PROPAGATION TESTS.

Propagation was obtained in test 215 with a mixture of 40 per cent coal dust and 60 per cent shale dust, with moderate pressures, but not in test 214 with a mixture of 30 per cent coal dust and 70 per cent shale dust. This latter mixture also failed to propagate in test 221 when there was 0.85 per cent gas in the air current. The flame extended 200 feet into the mixed dust. However, propagation would doubtless be obtained if more than 1 per cent of gas were present.

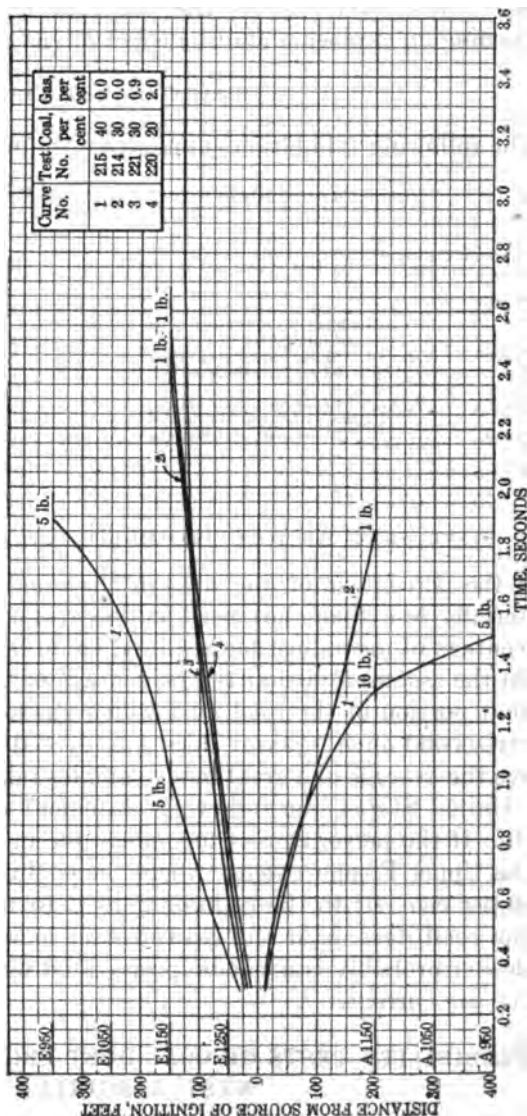


FIGURE 37.—Flame-velocity curves for standard propagation tests of mixtures of Upper Freeport coal dust and pit-shale dust. Figures in *italic* denote curve number, figures in roman denote pressure developed, in pounds per square inch, at that point.

Propagation was not obtained in test 220 with a mixture of 20 per cent coal dust and 80 per cent shale dust, with 2 per cent of gas in the ventilating current.

Figure 37 gives the flame-velocity curves of the four propagation tests. These curves show the effect of additional shale dust in quenching an explosion and the effect of gas present in aiding it.

SUMMARY OF RESULTS.

The following tabulation summarizes the results of the series:

Summary of results of tests of the Upper Freeport coal dust.

Approximate percentage of gas.	Ignition or propagation obtained.	Ignition or propagation not obtained.
None.....	Ignition was obtained with mixture containing—	Ignition was not obtained with—
1.....	50 per cent shale or less.....	60 per cent shale or more.
2.....	60 per cent shale or less.....	70 per cent shale or more.
3.....	70 per cent shale or less.....	70 per cent shale or more.
None.....	Propagation was obtained with—	Propagation was not obtained with—
1.....	60 per cent of shale or less.....	70 per cent shale or more.
2.....		70 per cent shale or more.
		80 per cent shale or more.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL TESTED.

If the percentage of fine sizes in the mine road-dust samples was materially less than that used in the tests, some reduction in the percentage of incombustible required could be made.

On the assumption that the percentage of 200-mesh dust and finer in that portion of the road dust which passes a 20-mesh sieve (one thirty-second inch square) does not exceed 40 per cent, which is above the average of a great many samples taken in mines throughout the United States, the following statement can probably be safely made: If the percentage of incombustible in the road dust of mines in the Upper Freeport seam, where the coal is similar to that tested, is 70 per cent, or in the ratio of 2 to 1, to the combustible content of the road dust, or if the road dust is so wet as to be plastic, an explosion probably can not be propagated even with 1 per cent gas in the air current.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE SEWELL BED, WEST VIRGINIA.

GENERAL CHARACTER OF TESTS.

A series of 11 explosion tests was made on 20-mesh and pulverized coal dusts prepared from a 5-ton sample of coal from the Sewell seam in the New River district of West Virginia. One set of tests was made with 20-mesh dust, 40 per cent of which would pass 200-mesh,

this size being selected as representing the dust in the mine. The object of this set was to determine whether or not dust of the size and composition found in the mine would sustain an explosion. A second set was made with the pulverized dust in order to obtain the maximum explosibility of the coal for comparison with that of coals from other mines. The tests were standard ignition and propagation tests, made according to the methods previously described.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

The testing sample was obtained from a mine in the New River district which produces the well-known semibituminous smokeless coal, such as that used for naval purposes. The mines of the district have experienced a number of disastrous explosions.

Standard road-dust samples and mine-air samples were collected from the mine in order to obtain information as to the size and character of the road dusts and on the amount of methane given off, in order that the conditions in the tests at the experimental mine might approach as nearly as possible the actual mine conditions.

Five standard face samples had been taken previously, the analyses of which are as follows:

Results of analyses of face samples of coal from a mine working the Sewell bed, West Virginia.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$
	Moisture.	Volatile matter.	Fixed carbon.	* Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
14294	3.00	25.22	68.25	3.50	6.50	26.98
14295	3.41	25.09	69.17	2.33	5.74	26.62
14296	3.11	26.03	67.32	3.54	6.65	27.89
14297	3.12	25.58	69.02	2.28	5.40	27.04
14299	3.17	25.24	67.89	3.70	6.87	27.10

The analysis of a composite sample prepared from the five samples was as follows:

Results of analysis of composite sample.

[Analysis made on basis of coal as received.]

Proximate analysis:

Moisture.....	per cent..	3.17
Volatile matter.....	do....	25.11
Fixed carbon.....	do....	68.81
Ash.....	do....	2.91
Moisture plus ash.....	do....	6.08
Ratio of volatile to total com- bustible.....		26.73

Ultimate analysis:

Hydrogen.....	per cent..	5.09
Carbon.....	do....	82.59
Nitrogen.....	do....	1.63
Oxygen.....	do....	7.26
Sulphur.....	do....	.52
Ash.....	do....	2.91

Nine samples of road dust were obtained; the results of analyses and sizing tests of these are as follows:

Results of analyses and sizing tests of road-dust samples from a coal mine in West Virginia working the Sewell bed.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio V V+FC	Screen test; cumulative percentage through—	
	Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
24205	1.81	18.73	50.37	29.09	30.90	27.10	32.1	20.3
24207	1.53	19.59	52.53	26.35	27.88	27.16	37.1	24.9
24208	1.44	22.76	50.59	15.21	16.65	27.30	32.5	21.9
24210	1.28	16.14	41.12	41.46	42.74	28.19	28.7	17.2
24609	.97	22.70	61.61	14.72	15.69	26.92	37.9	24.9
24359	1.87	22.47	59.46	16.20	18.07	27.43	35.9	23.4
24360	1.41	24.59	68.21	5.79	7.20	26.50	29.4	19.4
24361	1.33	24.96	63.69	10.02	11.35	28.16	31.6	20.3
24362	1.44	22.03	59.36	17.17	18.61	27.06	38.9	25.5

The content of ash and moisture in the road dusts ranges from 7.20 to 42.74 per cent, with an average of 21.01 per cent, and the content of 200-mesh dust ranges from 17.2 to 25.5 per cent, with an average of 22.0 per cent.

Analyses of a number of mine-air samples showed that the percentage of methane in the return air was very small, the highest content shown being 0.03 per cent, so that with reasonable care at the working faces the possibility of accumulation of gas forming should be small. On the other hand, it is not uncommon for mines in the New River district to encounter strong gas "blowers," a potential hazard.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

One propagation test was made with 20-mesh dust, about 20 per cent of which would pass 200-mesh. Two propagation tests were made with 20-mesh coal dust, 40 per cent of which would pass 200-mesh. No gas was used in any of these tests.

Four ignition tests were made with pulverized dust, two with gas present and two without gas.

Four propagation tests were made with pulverized dust, three with gas present and one without gas.

Pit-shale dust was used in these tests, 20-mesh shale dust being used with 20-mesh coal dust and pulverized shale dust with pulverized coal dust.

The average analyses of the Sewell coal dust as prepared for the test were as follows:

Results of average analyses of the Sewell coal dust as prepared for test.

		20-mesh dust.	Pulverized dust.
Moisture.....	per cent..	2.39	1.18
Volatile matter.....	do....	25.05	25.30
Fixed carbon.....	do....	66.80	68.05
Ash.....	do....	5.79	5.47
Moisture plus ash.....	do....	8.18	6.65
Ratio of volatile to total combustible.....		27.27	27.10

The pit-shale dust used in these tests had a total incombustible content of more than 99 per cent.

The average sizing tests of the coal dust and shale dust are as follows:

Average results of screen tests of coal dust and shale dust used.

Kind of dust.	Cumulative percentage through—			
	20-mesh.	48-mesh.	100-mesh.	200-mesh (screen A.).
20-mesh coal dust.....	95.2	75.8	57.3	40.0
Pulverized coal dust.....			99.6	77.3
20-mesh shale dust.....	86.9	58.7	39.8	25.9
Pulverized shale dust.....			99.9	94.6

In one test the Sewell seam coal dust was prepared so that about 95 per cent would pass 20-mesh and 21.5 per cent would pass 200-mesh.

The principal data on the explosion tests with this coal are presented in Table 31.

TABLE 31.—Results of standard tests of coal dust from the Sewell bed, West Virginia.

Originating cause: Standard blow-out shot from cannon at station E 1300. Sizes of coal dust used, 20-mesh dust, of which 20 per cent would pass 200 mesh, 20-mesh dust, of which 40 per cent would pass 200 mesh, and pulverized dust. Sizes of pit-shale dust used, 20-mesh and pulverized. In the ignition tests the mixed-dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 850, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.				
				Calculated combustible content.	Rate of loading.	Total loading.		Natural gas used.	Station 1150.	Station 950.	Fall at station 1250.	Fall at station 1150.	Fall at station 1050.	Fall at station 950.							
204	1916. Mar. 27	Pulverized.	50:50	53.2	4.00	2,800	0.0	$\left\{ \begin{array}{l} \text{Entry} \dots\dots 8 \\ \text{Air course} \dots\dots 6 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 7 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 6 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0.833 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 81 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.072 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 1.871 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 172 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.649 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 476 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.389 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Feet.} \\ 2.547 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Feet.} \\ 75 \end{array} \right.$	Ignition obtained.
281	Feb. 5	do.	40:60	62.6	5.00	3,500	.0	$\left\{ \begin{array}{l} \text{Entry} \dots\dots \\ \text{Air course} \dots\dots \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.502 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Feet.} \\ 75 \end{array} \right.$	Ignition not obtained.
286	Feb. 15	do.	40:60	62.6	5.00	3,500	.84	$\left\{ \begin{array}{l} \text{Entry} \dots\dots 3 \\ \text{Air course} \dots\dots 5 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 3 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 5 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 713 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 48 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.799 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.807 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 94 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 3.363 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 286 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 4.218 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 3.780 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Feet.} \\ 75 \end{array} \right.$	Ignition obtained.
283	Feb. 8	do.	30:70	71.8	3.33	2,333	2.00	$\left\{ \begin{array}{l} \text{Entry} \dots\dots 1 \\ \text{Air course} \dots\dots 3 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 1 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Lbs. per sq. in.} \\ 2 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 814 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 53 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.713 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 29 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0.106 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 2.340 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Sec. per sec.} \\ 0 \end{array} \right.$	$\left\{ \begin{array}{l} \text{Feet.} \\ 250 \end{array} \right.$	Ignition not obtained.

PROPAGATION TESTS.

287	1916. Feb. 17	20- mesh, 20 per cent 200- mesh	54.3	4.00	2,600	0.0	Entry..... {Air course.	4 2	5 4	0.457	237	0.909 .922	139 191	1.627 1.445	115 283	2.498 1.706	{ (e)	Propagation obtained.
288	Feb. 19	20- mesh, 40 per cent 200- mesh	62.9	5.00	3,250	.0	Entry..... {Air course.	3 2	3 3	.357	202	.832 .877	126 170	1.643 1.465	83 229	2.856 1.901	{ (e)	Do.
291	Feb. 26	do.....	72.5	3.33	2,167	.0	Entry..... {Air course.	1 1	1 1	.424	44	2.718 .....	.....	.....	.....	.....	{ 100 135	Propagation not obtained.
292	Feb. 5	Pulver- ized.	62.6	5.00	3,250	.0	Entry..... {Air course.	6 2	6 5	.428	171	1.013 .998	217 260	1.474 1.383	415 430	1.715 1.680	{ (e)	Propagation obtained.
294	Feb. 9	do.....	71.9	3.33	2,167	.78	Entry..... {Air course.	.....	.....	.....	.....	1.001 1.096	59 113	2.790 1.970	63	4.372	{ (e) 260	{ Propagation obtained in entry, but not in air course.
295	Feb. 14	do.....	76.5	4.00	2,600	1.56	Entry..... {Air course.	3 2	3 3	.342	201	.840 .836	91 138	1.934 1.561	139 138	2.635 2.940	{ (e)	Propagation obtained.
299	Feb. 21	do.....	81.5	5.00	3,250	1.80	Entry..... {Air course.	1 1	1 1	.....	.....	2.643 .....	.....	.....	.....	.....	{ 100 135	Propagation not obtained.

* Flame extended through zones.

DISCUSSION OF RESULTS.

PROPAGATION TESTS WITH 20-MESH DUST.

In test 287, with 20-mesh coal dust, of which 21.5 per cent would pass 200-mesh, propagation was obtained with a mixture of 50 per cent coal dust and 50 per cent shale dust when there was no gas in the air current. The pressures at stations E 950 and A 950 were 5 and 4 pounds, respectively. Judging from the pressures and velocities resulting from this test, it may be assumed that propagation probably could not be obtained with a mixture of 40 per cent coal dust and 60 per cent shale dust of this size.

In test 288 a mixture of 40 per cent 20-mesh coal dust, of which 40 per cent passed through 200-mesh, and 60 per cent shale dust was used. Inasmuch as the road-dust samples from this mine contained a maximum of 25.5 per cent of 200-mesh dust, and rib dusts, as a rule, contain a greater percentage of 200-mesh dust than road dust, it seemed desirable that dust having a somewhat greater percentage of fine sizes be used in order to have some margin of safety in applying the results to field conditions. Propagation was obtained with this mixture, but could not be obtained in test 291 with the same size of dust with a mixture of 30 per cent coal dust and 70 per cent shale dust.

IGNITION TESTS WITH PULVERIZED DUST.

In test 304 ignition was obtained with a 50 per cent coal dust and 50 per cent shale dust mixture. In test 281 ignition was not obtained with a 40 per cent coal-dust and 60 per cent shale-dust mixture. However, in test 286, with a mixture having the same percentages and with 0.84 per cent natural gas in the air current, ignition was obtained. Ignition was not obtained in test 283 with a mixture of 30 per cent coal dust and 70 per cent shale dust, with 2 per cent gas present. This indicates that the increase in the percentage of shale dust more than offset the increase in the percentage of gas.

PROPAGATION TESTS WITH PULVERIZED DUST.

Propagation was obtained in test 282 with a mixture of 40 per cent coal dust and 60 per cent shale dust, but was not obtained in test 284 with a mixture of 30 per cent coal dust and 70 per cent shale dust, with 0.78 per cent natural gas in the air current. In the latter test the flame in the entry extended throughout the zone, but that in the air course extended only 250 feet. A slightly increased percentage of natural gas would probably have permitted propagation in both zones.

In test 285 propagation was obtained with a mixture of 25 per cent coal dust and 75 per cent shale dust when there was an average of 1.56 per cent natural gas in the air current. Propagation, however, could not be obtained with a mixture of 20 per cent coal dust

and 80 per cent shale dust when there was an average of 1.9 per cent natural gas in the air current.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

The following table shows the amount of incombustible material necessary to prevent ignition and propagation under various test conditions, on the assumption that the starting arrangements are equivalent to those at the experimental mine:

Proportions of incombustible needed to prevent ignition or propagation in mixtures with the Sewell coal dust.

Size of dust.	Gas.	Nonignition.		Nonpropagation.	
		Incombustible.	Shale.	Incombustible.	Shale.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
20-mesh, 20 per cent through 200-mesh	0	63	60	63	60
20-mesh, 40 per cent through 200-mesh	0	72	70	72	70
Pulverized	0	63	60	72	70
Do.	1	72	70	82	80
Do.	2	72	70	82	80

APPLICATION TO FIELD CONDITIONS.

The tests in the experimental mine showed that with 20-mesh dust, of which 20 per cent would pass 200-mesh, 63 per cent of incombustible material prevented propagation in the absence of gas. However, as the dust from this mine has a somewhat larger proportion of fine dust, the use of a higher percentage—say 65 per cent—of incombustible material would be safer.

Examination of the road-dust samples shows that none of them contains this much moisture plus ash, and consequently all of them are explosive. The ratios of incombustible material to be added to the dusts already in the mine in order to obtain the desired total of 65 per cent are given in the following table:

Data showing additions of incombustible material needed to make the road dusts non-explosive.

Laboratory No. of sample.	Content of moisture plus ash in sample.	Desired percentage of incombustible.	Ratio of incombustible material to be added to dust already in mine.
	Per cent.		
24205	30.90	65	0.97
24207	28.88	65	1.08
24208	16.65	65	1.38
24210	42.74	65	.64
24609	15.69	65	1.41
24359	18.07	65	1.34
24380	7.20	65	1.65
24361	11.35	65	1.53
24362	18.61	65	1.32

Therefore in order that the dust from this mine be nonexplosive an analysis of that portion of the dust passing a 20-mesh screen should show at least 65 per cent of moisture plus ash, or, if dependence is placed on wetting to render the coal dust inert, the dust must be thoroughly wetted by frequent washings in such manner as to remove all the fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM A BITUMINOUS COAL, CROW'S NEST FIELD, BRITISH COLUMBIA.

A series of 10 tests was made of 20-mesh and pulverized dusts prepared from a 3½-ton sample of run-of-mine coal obtained from a mine in British Columbia, working a bituminous coking coal bed. The tests with 20-mesh dust were made to determine if it was possible for dust of the size and composition of that found in the mine to ignite and sustain an explosion. The tests with pulverized dust were made for comparison with the coals from other mines. These tests were standard ignition and propagation tests.

This testing, as well as that of coal dust from a mine in Vancouver Island (see p. 229) was undertaken at the request of the Department of Mines of British Columbia. The samples were gathered in the respective mines by an inspector of the province. The coals in the Coal Creek district of the Crow's Nest field are very gaseous, ethane being given off on crushing the coal, according to the Annual Report, 1917, of the Minister of Mines of British Columbia.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Examination was made to determine the composition of the coal, the size and character of the road dusts, and the presence of methane, in order that the tests in the experimental mine might have conditions as nearly as possible like those in the mine from which the dust came.

Four standard face samples of the coal were taken, the analyses of which are given in the following table. The analyses of samples 27155 and 27157 are reported on the basis of coal "as received," whereas those on Nos. 27154 and 27156 are reported on the basis of coal "air dried." The air drying removes part of the moisture.

Results of analyses of face samples of a semibituminous coal from a mine in British Columbia.

Laboratory No. of sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Moisture plus ash.	Ratio V V+FC
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
27155	1.05	23.12	63.22	12.55	13.66	26.78
27157	1.58	21.12	64.54	12.94	14.52	24.71
27154	.55	24.78	65.17	9.50	10.05	27.55
27156	.40	24.23	66.52	8.85	9.25	26.70

Ten road-dust samples and ten rib-dust samples were taken in the mine, the analyses and sizing tests of which were as follows:

Results of analyses and sizing tests of the road dusts and rib dusts from a mine in British Columbia.

Laboratory No. of sample.	Kind of dust.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Moisture plus ash.	Ratio V V+FC	Screen test of 20- mesh dust; cu- mulative percent- age through—	
								100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
27172....	Road dust.	6.47	22.06	61.06	10.30	16.86	26.56	26.6	11.3
27174....	do.....	1.47	23.43	63.21	11.80	13.36	27.04	44.5	27.0
27176....	do.....	1.56	23.45	63.90	11.09	12.65	26.85	43.9	25.1
27178....	do.....	.94	23.80	62.48	12.78	13.72	27.58	40.4	24.4
27180....	do.....	1.03	25.42	61.35	12.20	13.23	29.29	45.6	5.3
27182....	do.....	1.33	25.09	60.84	12.74	14.07	29.20	32.6	17.0
27184....	do.....	1.25	25.45	61.55	11.75	13.00	29.25	49.1	7.4
27186....	do.....	1.25	24.55	60.89	13.31	14.56	28.73	47.8	27.6
27188....	do.....	1.34	25.24	58.15	15.27	16.61	30.27	41.4	3.5
27190....	do.....	2.43	25.86	53.60	18.11	20.54	32.54	58.7	13.3
27173....	Rib dust.	2.34	22.98	63.29	11.39	13.73	26.64	48.4	33.1
27175....	do.....	2.01	22.99	63.11	11.89	13.90	26.70	55.3	42.8
27177....	do.....	1.52	24.28	63.05	11.15	12.67	27.80	66.4	58.4
27179....	do.....	1.27	25.74	57.17	15.82	17.09	31.04	66.5	57.7
27181....	do.....	1.47	24.71	57.02	16.80	18.27	30.23	66.1	28.5
27183....	do.....	1.09	25.66	62.51	10.74	11.83	29.10	81.2	74.2
27185....	do.....	.89	24.49	61.11	13.51	14.40	28.61	70.6	56.0
27187....	do.....	1.19	21.18	45.26	32.37	33.56	31.87	67.2	53.2
27189....	do.....	1.40	24.51	59.52	14.57	15.97	29.17	58.9	44.4
27191....	do.....	1.83	25.16	59.04	13.97	15.80	29.88	79.7	71.8

The moisture and ash content of the road-dust and rib-dust samples ranged from 11.83 per cent to 33.56 per cent, the average being about 15 per cent; the percentage of 200-mesh dust in the combined road and rib samples ranged from 8.3 per cent to 38.6 per cent.

As half of the combined road, rib, and roof samples contained more than 30 per cent of dust that would pass through a 200-mesh screen, one combined sample containing 38.6 per cent of dust finer than 200-mesh, the tests on this coal were made with 20-mesh dust, of which 40 per cent would pass through 200-mesh.

Gas is encountered in this mine in considerable quantities and special precautions are taken to guard against it, but any system for rendering the coal dust inert should take into account the presence of gas, the return air currents sometimes carrying over 2 per cent methane.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Four ignition tests were made—two with pulverized dust and two with 20-mesh dust, all without gas. One propagation test was made with pulverized dust, with no gas in the ventilating current. Five propagation tests were made with 20-mesh dust, two being without

gas and three with additions of gas ranging from 0.96 per cent to 2.29 per cent in the ventilating current.

The average analysis of the pulverized and the 20-mesh—40 per cent through 200-mesh—British Columbia coal dust used in these tests was as follows:

Average results of analyses of pulverized and 20-mesh coal dust used.

	Pulver- ized dust.	20-mesh dust.
Moisture.....per cent..	0.70	1.23
Volatile matter.....do....	23.52	23.70
Fixed carbon.....do....	65.01	64.09
Ash.....do....	10.77	10.98
	100.00	100.00
Ratio of volatile to total combustible.....	26.57	27.00

The average analysis of the shale dust used in these tests showed a moisture content of 1.44 per cent and of total incombustible 99.30 per cent.

The average sizing tests of the coal dust and shale dust were as follows:

Results of average sizing tests of coal dust and shale dust used.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	Per cent.	Per cent.	Per cent.	Per cent.
Pulverized coal dust.....			99.6	88.4
20-mesh (40 per cent through 200-mesh) coal dust.....	99.0	81.1	53.9	40.0
Pulverized shale dust.....			100.0	98.2
20-mesh shale dust.....	86.0	58.8	36.1	25.7

The average sizing tests on the pulverized Pittsburgh coal dust used in the ignition zone in the propagation tests showed 98.4 per cent through 100-mesh and 76.4 per cent through 200-mesh. The average analysis of this Pittsburgh coal dust gave a moisture and ash content of 7.14 per cent and a ratio of volatile combustible to total combustible of 39.91 per cent.

The principal data in connection with the tests are presented in Table 32.

DISCUSSION OF RESULTS.

IGNITION TESTS.

Ignition was not obtained in test 387 with a mixture containing 50 per cent pulverized coal dust and 50 per cent shale dust, but was obtained in test 386 with a mixture of 60 per cent pulverized coal dust and 40 per cent shale dust, there being no gas in the ventilating current in either test.

With 20-mesh coal dust (40 per cent of which would pass 200-mesh) ignition was not obtained in test 381 with a mixture of 70 per cent coal dust and 30 per cent shale dust, with no gas present. However, as the flame traveled 150 feet in the main entry and 225 feet in the air course, a mixture of 80 per cent 20-mesh coal dust and 20 per cent 20-mesh shale dust would very likely give ignition.

PROPAGATION TESTS.

With pulverized coal dust an explosion was obtained in test 388 with a mixture containing 50 per cent coal dust and 50 per cent shale dust. The pressures and velocities developed in this test indicate that 10 per cent more shale dust (10 per cent less coal dust) would be very near the limiting mixture, if not actually preventing propagation.

With 20-mesh coal dust propagation was not obtained in test 382 with a mixture of 50 per cent coal dust and 50 per cent shale dust, but was obtained in test 384 with a mixture of 60 per cent coal dust and 40 per cent shale dust.

Propagation was obtained in test 389 with a mixture of 40 per cent 20-mesh coal dust and 60 per cent shale dust, with 1.0 per cent natural gas in the ventilating current, and propagation was also obtained in test 385 with a mixture of 30 per cent coal dust and 70 per cent shale dust, with 2.3 per cent natural gas in the ventilating current. The pressures and velocities of these tests indicate that a mixture of 30 per cent 20-mesh coal dust and 70 per cent 20-mesh shale dust would not propagate when there is not more than 1 per cent of gas in the ventilating current. It is also probable that propagation would not be obtained with a mixture of 25 per cent 20-mesh coal dust and 75 per cent 20-mesh shale dust, with 2 per cent of gas in the ventilating current.

These tests indicate the characteristic of explosibility manifested by dusts from coals of the semibituminous class having ratios of volatile to total combustible of less than 30 per cent. This characteristic is a lower limit of explosibility when no inflammable gas is present, but when it is present in small percentages, the limits are raised more markedly than are those of a dust with an inherently high ratio.

TABLE 32.—Results of standard tests of coal dust from a semibituminous bed in British Columbia.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used, 20-mesh, of which 40 per cent would pass 200-mesh, and pulverized. Size of pit-shale dust used, 20-mesh, and pulverized. In the ignition tests the mixed dust was loaded in the first 50 feet from the cannon at double the rate used in the rest of the zone and given in the table. The mixed-dust zones extended from stations E 1300 to E 960, 350 feet, and from stations E 1260 to A 960, 350 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1260 to E 960, 300 feet, and from stations E 1250 to A 960, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.		Records obtained in entry or in air course.	Maximum pressure.		Time of tin-fall rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.		
				Calculated incom-tible content.	Rate of head-ing.		Total load-ing.	Natu-rales used.	Station 1150.	Station 950.	Fall at station 1250.	Ve-locity. 1250.	Fall at station 1150.	Ve-locity. 1150.			Fall at station 1050.	Ve-locity. 1050.	Fall at station 950.	Ve-locity. 950.
381	1917. Feb. 23	20-mesh	70:30	Per cent. 39.0	Lbs. per ft. 1.43	Lbs. 1,071	Per cent. 0.0	Lbs. per sq. in. 1	Lbs. per sq. in. 1	Sec-onds. 0.450	40	Sec-onds. 2.980	1.831	Sec-onds.	Sec-onds.	Sec-onds.	Feet. 150 225	} Ignition not obtained.
380	Feb. 20	...do....	60:40	47.3	1.67	1,260	.0	1	1	.....	.....	.....	.....	.....	.....	.....	50 75		Do.
386	Mar. 5	Pulver-ized.	40:40	47.2	1.67	1,260	.0	8	12	1.464	510	1.660	1.649	186	2.192	1,754	2.249 2.140	} Ignition obtained.
387	Mar. 7	...do....	50:50	55.6	2.00	1,500	.0	1	1	4.082	.....	.....	.....	.....	.....	.....	75 75		} Ignition not obtained.

PROPAGATION TESTS.

[illegible]

b Flame velocity and pressure curves of this test are shown in figure 71

Flame extended through zones.

b Flame velocity and pressure curves of this test are shown in figure 71

PROPORTION OF INERT MATERIAL NEEDED TO PREVENT PROPAGATION OR IGNITION.

The following table summarizes the amount of incombustible material or admixed shale dust necessary to prevent ignition and to prevent propagation under the various conditions when dust is 20-mesh size, of which 40 per cent or less will pass 200-mesh.

Data showing amount of incombustible needed to render the coal dust nonexplosive.

	Gas present.	Incombustible.	Shale dust.
	Per cent.	Per cent.	Per cent.
Nonignition.....	0	30	30
Nonpropagation.....	0	56	50
Do.....	1	73	70
Do.....	2	78	75

APPLICATION TO FIELD CONDITIONS.

The tests in the experimental mine indicate that under the conditions of test it would be necessary to have 78 per cent or more of incombustible material in the road and rib dusts to prevent the propagation of an explosion with 2 per cent gas in the ventilating current. Examination of the road and rib dust samples shows that none of these contain the required amount of moisture and ash, this being counted as incombustible material. The ratio of incombustible dust that must be added to the dust already in the mine in order to obtain the desired percentage of incombustible material in the road and rib dusts is given in the following table:

Data showing additions of inert material needed to make the mine dusts nonexplosive.

Laboratory No. of sample.	Kind of dust.	Moisture and ash.	Incombustible desired.	Ratio of incombustible dust to be added.
		Per cent.	Per cent.	
27172	Road dust	16.86	78	2.78
27174	do.	13.36	78	2.94
27176	do.	12.65	78	2.97
27178	do.	13.72	78	2.92
27180	do.	13.23	78	2.94
27182	do.	14.07	78	2.91
27184	do.	13.00	78	2.95
27186	do.	14.56	78	2.88
27188	do.	16.61	78	2.79
27190	do.	20.54	78	2.61
27173	Rib dust.	13.73	78	2.92
27175	do.	13.90	78	2.91
27177	do.	12.67	78	2.97
27179	do.	17.09	78	2.77
27181	do.	18.27	78	2.72
27183	do.	11.83	78	3.01
27185	do.	14.40	78	2.89
27187	do.	33.56	78	2.02
27189	do.	15.97	78	2.82
27191	do.	15.80	78	2.83

In order, therefore, that the mine dust be nonexplosive in the presence of 2 per cent of gas, the analysis of that portion of the dust passing through a 20-mesh screen should show at least 78 per cent of moisture and ash. If dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washings in such a manner as to remove all fine dusts from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE LOWER KITTANNING, B, OR MILLER BED, CLEARFIELD COUNTY, PA.

A series of eight explosion tests was made on 20-mesh and pulverized dust prepared from a 5-ton sample of run-of-mine coal obtained from a mine in central Pennsylvania working the Miller seam. The object of the series was to determine the relative explosibility of this coal dust as compared with coal dusts from other seams, and to determine whether dust of the size and composition found in the mine would propagate an explosion. The tests were standard ignition and propagation tests.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

A field investigation was made of the conditions in the mine to obtain information as to the composition of the coal, the size and composition of the road and rib dusts, and the presence of methane, in order that the tests in the experimental mine might approach as nearly as possible the actual conditions in the mine sampled.

Four standard face samples were taken, the analyses being as follows:

Results of analyses of face samples of coal from a mine working the Miller seam, Pennsylvania.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
26306	2.92	23.08	64.60	9.36	12.28	26.25
26307	3.68	21.97	64.63	9.72	13.40	25.37
26308	2.61	24.61	62.96	9.83	13.44	28.11
26309	2.77	22.83	65.61	8.79	11.56	25.81

A composite sample of the four standard face samples gave the following analysis of this semibituminous coal:

Results of analysis of composite sample of face coal.

[Analysis made on basis of coal as received.]

Proximate analysis:

Moisture.....per cent...	3.01
Volatile matter.....do....	22.84
Fixed carbon.....do....	64.62
Ash.....do....	9.53
Moisture plus ash.....do....	12.54
Ratio of volatile to total combustible.....	26.12

Ultimate analysis:

Hydrogen.....per cent...	4.71
Carbon.....do....	76.69
Nitrogen.....do....	1.31
Oxygen.....do....	4.67
Sulphur.....do....	3.09
Ash.....do....	9.53

Five standard samples each of rib and road dust were taken from the entries in various parts of the mine. The dust was screened through a 10-mesh screen unless very damp, when a one-half inch screen was used. The undersize was retained for further screening in the laboratory, and for analysis.

The following table shows results of analyses and sizing tests of the road-dust and rib-dust samples:

Results of analyses and screen tests of samples of road and rib dust, 20 mesh and finer.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio V. + F.C.	Cumulative percentage.	
	Moisture.	Volatile matter.	Fixed carbon.	Ash.			Through 100-mesh screen.	Through 200-mesh screen.
<i>Road dust.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
26313	5.58	22.67	55.21	16.54	22.12	29.11	7.3	2.4
26314	10.13	21.62	61.06	17.19	27.82	29.75	15.4	7.3
26315	7.48	21.42	52.57	18.53	28.00	28.66	14.3	2.5
26316	7.41	21.47	56.40	14.72	22.13	27.58	4.4	0.6
26317	7.78	16.88	43.32	32.02	39.80	28.08	4.1	1.3
<i>Rib dust.</i>								
26318	6.13	22.98	54.31	16.58	22.71	29.73	13.6	3.9
26319	8.25	22.31	41.61	27.75	36.08	34.91	16.6	5.0
26320	7.40	22.98	54.65	14.97	22.37	29.61	3.4	0.9
26321	6.73	21.79	58.06	13.42	20.15	27.29	15.0	3.6
26322	9.55	21.63	52.38	16.44	25.99	29.22	5.9	2.2

The moisture and ash content of the road and rib samples averaged between 25 and 30 per cent, and the percentage of 100-mesh and 200-mesh dust was comparatively low, being about 10 and 3 per cent, respectively.

Air samples were taken in the returns and at a dead end in the face of one entry. Only a trace of methane (0.01 per cent) was found.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

One ignition test was made with pulverized dust (89.8 per cent through a 200-mesh sieve). Two ignition tests and two propagation tests were made with 20-mesh dust, 20 per cent of which would pass through 200-mesh; one ignition test and two propagation tests were made with 20-mesh dust, 10 per cent of which would pass through 200-mesh. No gas was used in any of the tests.

The average analysis of the Miller seam coal dust used in these tests was as follows:

Average composition of the coal dust.

Moisture.....	per cent..	1. 50
Volatile matter.....	do....	22. 63
Fixed carbon.....	do....	66. 46
Ash.....	do....	9. 41
Ratio of volatile to total combustible.....		25. 40

The average analysis of the pit-shale dust used in these tests showed moisture, 1.71 per cent, and total incombustible, 99.54 per cent.

The average results of screen tests of the coal dust and shale dust as prepared for the tests were as follows:

Average results of sizing tests of the coal dusts and the shale dusts used.

Material.	Through 20- mesh.	Through 48- mesh.	Through 100- mesh.	Through 200- mesh.
	Per cent.	Per cent.	Per cent.	Per cent.
Pulverized coal dust.....			99. 4	89. 8
20-mesh coal dust, 20 per cent through 200-mesh.....	95. 5	67. 2	37. 5	20. 7
20-mesh coal dust, 10 per cent through 200-mesh.....	95. 4	59. 5	28. 0	10. 0
Pulverized shale dust.....			100. 0	97. 6
20-mesh shale dust.....	87. 0	60. 7	37. 4	27. 8

The results of the explosion tests are presented in Table 33.

TABLE 33.—*Results of standard tests on coal dust from the B, or Miller bed, Clearfield County, Pa.*

[Originating cause: Standard blown-out shot from cannon at station E 1300. Sizes of coal dust used: 20-mesh dust, of which 10 per cent would pass 200-mesh; 20-mesh dust, of which 20 per cent would pass 200-mesh, and pulverized dust. Sizes of pit-shale dust used—20-mesh and pulverized. In the ignition tests the mixed-dust zones extended from stations E 1300 to E 960, 350 feet, and from stations E 1250 to A 960, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet, the mixed-dust zones extended from stations E 1250 to E 960, 30 feet, and from stations E 1250 to A 960, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Mixed dust.			Records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.	
			Ratio of coal dust to shale dust in mixture.	Calculated combustible content.	Rate of loading.		Total loading.	Station 1150.	Station 960.	Fall at station 1250.	Velocity.	Fall at station 1150.	Velocity.	Fall at station 1050.			Velocity.	Fall at station 960.
				Per cent.	Lbs. per ft.	Lbs.	Entry—Air course.	Lbs. per sq. in.	Lbs. per sq. in.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.
247 ^c	1916. Nov. 17	20-mesh, 20 per cent 200-mesh.	}	(a)	10.9	1,400	Entry—Air course.	49	127	0.669	0.963	0.855	1,143	0.796	3,946	0.800	Violent ignition obtained.
248	Nov. 15	do.....				2,000	Entry—Air course.	28	24	0.649	332	0.960	1.037	587	1,087	1.210	2,128	1.257	Ignition obtained.
257	Dec. 11	20-mesh, 10 per cent 200-mesh.	1,000	Entry—Air course.	5	6	.832	97	1.831	1.890	113	2,769	318	2.443	1,149	2.083	Do.
259	Dec. 15	Pulverized.....	1,750	Entry—Air course.	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	25 Ignition not obtained.

PROPAGATION TESTS.

1916. Nov. 24	20-mesh, 10 per cent 200-mesh.	60 : 40	46.5	3.33	2,167	(Entry..... (Air course.	17 19	14 24	0.417	333	0.717 .662	461 350	0.934 .948	535 676	1.121 1.096	(c) (c)	(Propagation obtained.
354 Dec. 4	do.....	50 : 50	55.4	2.00	1,300	(Entry..... (Air course.	3 3	3 2	.420	177	.948 1.052	128 182	1.799 1.661	111 277	2.698 1.962	(c) (c)	Do.
345 Nov. 13	20-mesh, 20 per cent 200-mesh.	50 : 50	55.5	4.00	2,600	(Entry..... (Air course.	17 17	13 21	..... .....	..... .....	.832 .753	357 322	1.112 1.064	971 741	1.215 1.190	(c) (c)	Do.
348 Nov. 20	do.....	40 : 60	64.4	2.50	1,025	(Entry..... (Air course.	3 2	3 2	.421	47	2.550 1.028	127 67	3.339 2.524	..... .....	..... .....	225 (c)	(Propagation obtained in air course, but not in entry.

c All coal.

s Flame extended through zones.

c Flame velocity and pressure curves of this test shown in figure 60.

DISCUSSION OF RESULTS.

IGNITION TESTS.

With pulverized dust ignition was not obtained in test 359 with a mixture of 40 per cent coal dust and 60 per cent shale dust.

With a mixture of 70 per cent 20-mesh coal dust, of which 10 per cent would pass through 200-mesh, and 30 per cent 20-mesh shale dust, an ignition was obtained. Pressures developed in this test (No. 357) were low and indicate that a slightly greater percentage of shale would prevent ignition.

In test 347 a violent ignition was obtained with pure 20-mesh Miller coal dust, 20 per cent of which would pass 200-mesh. Strong ignition was also obtained in test 346 with a mixture comprising 70 per cent 20-mesh coal dust, 20 per cent of which would pass 200-mesh, and 30 per cent 20-mesh pit-shale dust.

PROPAGATION TESTS.

Propagation was obtained in test 354 with a mixture of 50 per cent 20-mesh coal dust, of which 10 per cent would pass through 200-mesh, and 50 per cent shale dust, but was not obtained in test 348 through a mixture of 40 per cent 20-mesh coal dust, 20 per cent of which would pass 200-mesh and 60 per cent 20-mesh shale dust; consequently a mixture having 40 per cent of the 20-mesh coal dust, 10 per cent of which would pass 200-mesh, would not be explosible.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

With 20-mesh dust, 10 per cent of which would pass 200-mesh, it is necessary, under conditions as in the experimental mine, to have 40 per cent admixed shale dust or 47 per cent incombustible material to prevent ignition, and to have 60 per cent admixed shale dust or 65 per cent incombustible material to prevent propagation in the absence of gas.

APPLICATION TO FIELD CONDITIONS.

The tests show that to prevent the propagation of an explosion already originated it is necessary that the dust from the mine sampled have a total incombustible or moisture plus ash content of about 65 per cent. As none of the road or rib dust samples contained this amount of incombustible, all of them are explosive. The rate of incombustible dust to be added to the dust already in the mine in order that the desired percentage of incombustible material be present is shown in the following table:

Data showing additions of inert dust necessary to render harmless the mine dust of a coal mine working the Miller bed, Pennsylvania.

Laboratory No. of sample.	Kind of dust.	Moisture plus ash.	Desired percentage of incombustible.	Ratio of incombustible dust to be added to dust in mine.
		<i>Per cent.</i>		
26313	Road dust...	22.12	65	1.22
26314	do.....	27.32	65	1.07
26315	do.....	26.00	65	1.11
26316	do.....	22.13	65	1.22
26317	do.....	39.80	65	.72
26318	Rib dust...	22.71	65	1.21
26319	do.....	36.06	65	.83
26320	do.....	22.37	65	1.22
26321	do.....	20.15	65	1.28
26322	do.....	25.99	65	1.11

Therefore in order that the mine dust be nonexplosive in the absence of gas an analysis of that portion of the dust passing through a 20-mesh screen should show 65 per cent or more of moisture plus ash, or, if dependence is placed on wetting for rendering the coal dust inert, it should be thoroughly wetted by frequent washing in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE FIRE CREEK BED, WEST VIRGINIA.

A series of nine explosion tests (ignition and propagation) was made with pulverized dust, prepared from a 5-ton sample of coal obtained from a mine in the New River district, West Virginia, working the Fire Creek seam. The object of this series was to determine the percentage of shale necessary to prevent ignition and to prevent propagation of an explosion under standard test conditions, both with and without gas in the ventilating current. These tests were made before the use of 20-mesh coal dust for testing was adopted; consequently all the tests were with pulverized dust.

The New River district produces a widely known semibituminous smokeless coal. The mines of the district, in which have occurred several disastrous explosions, are generally free from noticeable amounts of gas, but methane blowers or feeders are not infrequently encountered.

CONDITIONS IN MINE FROM WHICH SAMPLE WAS OBTAINED.

Examination was made of the mine from which this sample was procured. Samples of the coal, road dust, rib dust, and mine air were taken in order to determine what conditions in the experimental mine would most nearly approximate the actual mine conditions.

Five standard face samples of coal were taken from the mine. The results of analyses of these samples is given in the following table:

Results of analyses of face samples of coal from a mine working the Fire Creek bed, West Virginia.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
21502	3.02	20.63	70.23	6.12	9.14	22.70
21503	2.21	20.21	70.34	7.24	9.45	22.32
21504	2.92	20.62	70.03	6.43	9.35	22.75
21505	2.70	19.64	71.64	6.02	8.72	21.51
21506	4.04	19.07	68.83	8.06	12.10	21.69

The analysis of a composite of these samples is as follows:

Results of analysis of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....	per cent..	2.90
Volatile matter.....	do....	20.55
Fixed carbon.....	do....	69.72
Ash.....	do....	6.83
Moisture plus ash.....	do....	9.73
Ratio of volatile to total combustible.....		22.76

Ultimate analysis:

Hydrogen.....	per cent..	4.84
Carbon.....	do....	81.25
Nitrogen.....	do....	1.58
Oxygen.....	do....	4.64
Sulphur.....	do....	.86
Ash.....	do....	6.83

Fifteen road dust and two rib dust samples were taken. The analyses and sizing tests of these samples are given in the following table:

Composition and fineness of the road and rib dusts from a mine working the Fire Creek bed, West Virginia.

Laboratory No. of sample.	Kind of dust.	Analysis as received.				Moisture plus ash.	Ratio $\frac{V}{V+FC}$	Screen test; cumulative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh.	200-mesh (screen A).
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
21514....	Road dust.	5.05	18.46	65.00	11.49	16.54	22.12	45.4	33.4
21517....	do.....	.98	18.68	65.35	14.99	15.97	22.22	.....	.....
21519....	do.....	10.66	14.32	50.43	24.69	36.25	23.12	.....	.....
21516....	do.....	10.11	16.85	60.50	12.54	32.65	21.79	.....	.....
21512....	do.....	6.15	18.64	60.77	14.54	20.69	23.37	34.2	18.6
21522....	do.....	1.14	17.27	59.04	22.55	23.69	22.63	.....	.....
21518....	do.....	7.18	15.51	59.87	17.44	24.62	20.58	68.5	57.1
21515....	do.....	4.59	16.96	60.04	18.41	26.00	22.03	36.2	22.8
21520....	do.....	5.32	9.14	31.54	54.00	59.32	22.46	.....	.....
21524....	do.....	2.53	15.85	55.90	26.02	28.55	22.12	47.1	33.6
21523....	do.....	3.83	17.41	59.52	19.24	23.07	22.63	.....	.....
21526....	do.....	3.07	16.91	70.19	9.83	12.90	19.42	25.7	16.0
21527....	do.....	11.66	12.79	43.01	27.54	38.20	21.04	.....	.....
21521....	do.....	6.81	14.75	49.37	29.07	35.88	23.01	.....	.....
21515....	do.....	.95	20.45	65.87	11.73	12.68	23.42	.....	.....
21525....	Rib dust.	2.86	15.52	57.30	24.32	27.18	21.32	.....	.....
21529....	do.....	7.85	15.64	63.02	13.49	21.34	19.98	.....	.....

The content of moisture and ash in the mine dusts ranged from 12.68 to 59.32 per cent, that of the moisture alone varying from 0.95 to 11.66 per cent.

Ten samples of mine air were obtained. These showed little or no methane, the maximum being 0.2 per cent. The main returns showed less than 0.1 per cent of methane in the air.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Six ignition tests were made, three being without gas and three with gas in the ventilating current. Three propagation tests were made, two without gas and one with gas. All tests were made with pulverized coal dust, and pulverized pit shale dust was used in the mixtures.

The average analysis of the pulverized Fire Creek coal dust as prepared for the tests was as follows:

Results of average analysis of the coal dust.

Moisture.....	per cent..	1. 00
Volatile matter.....	do....	20. 27
Fixed carbon.....	do....	71. 34
Ash.....	do....	7. 39
		100. 00
Moisture plus ash.....	do....	8. 39
Ratio of volatile to total combustible.....		22. 13

The average sizing test of the coal dust showed 99.2 per cent through 100-mesh, 89.6 per cent through 200-mesh (screen A), and 72.8 per cent through 240-mesh.

The pulverized pit-shale dust used in the mixtures in these tests had a total incombustible content of more than 99 per cent, and screen analyses showed that more than 96 per cent would pass through 200-mesh.

The principal data on the explosion tests are presented in Table 34.

TABLE 34.—*Results of standard tests of coal dust from the Fire Creek bed, West Virginia.*

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used: Pulverized. Size of pit-shale dust used: Pulverized. In the ignition tests the mixed-dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Natural gas used.	Records obtained in entry or in air course.	Maximum pressure.		Time of tin-fall rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
			Calculated incombustible content.	Rate of loading.	Total loading.			Station 1150.	Station 950.	Fall at station 1250.	Ve-locity.	Fall at station 1150.	Ve-locity.	Fall at station 1080.	Ve-locity.	Fall at station 950.	
			Per cent.	Lbs. per ft.	Lbs.	Per cent.	{Entry..... {Air course.....	Lbs. per sq. ft.	Lbs. per sq. ft.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	
237	1915. Oct. 18	(c)	7.6	2.00	1,400	0.0	{Entry..... {Air course.....	35 39	44 76	0.414	407	0.680	1,123	0.773	1,722	0.785	Ignition obtained.
242	Nov. 9	60:40	45.6	3.33	2,333	.0	{Entry..... {Air course.....	12 10	8	.976	94	2.037	256 336	2.428 2.315	430 794	2.648 2.441	Do.
245	Nov. 16	50:50	54.2	4.00	2,800	.0	{Entry..... {Air course.....	1 1	1	.754	23	5.027 .....	.....	.....	.....	.....	Ignition not obtained.
239	Oct. 27	50:50	54.4	4.00	2,800	1.02	{Entry..... {Air course.....	6 4	7 6	.883 .....	.....	2.233	85 145	2.220 2.924	633 370	3.307 3.194	Ignition obtained.
238	Oct. 22	40:60	63.05	5.00	3,500	2.33	{Entry..... {Air course.....	23 13	13 20	.831	108	1.752 1.633	445 444	1.987 1.878	1,613 1,298	2.020 1.945	Do.
240	Nov. 2	30:70	72.6	5.00	3,500	2.12	{Entry..... {Air course.....	 1	0 0	..... .....	..... .....	..... .....	..... .....	..... .....	..... .....	..... .....	Ignition not obtained.

PROPAGATION TESTS.

	1915. Nov. 16	50:50	54.2	4.00	2,000	0.0	Entry..... { Air course.	22 26	 27	0.417	450	0.639 .604	1,538 535	0.704 .791	1,538 704	0.769 .832	(b)	Propagation obtained.
246	Nov. 19	40:60	63.2	5.00	3,260	.0	Entry..... { Air course.	1 1	 1	.351	88	1.555 1.570	50	3.546 .....	.....	.....	250 125	Propagation not ob- tained.
241	Nov. 3	30:70	72.6	5.00	3,260	1.62	Entry..... { Air course.	 1	1 1	.493	27	4.171 .....	.....	.....	.....	.....	75 100	Do.

a All coal.

b Flame extended through zones.

DISCUSSION OF RESULTS.

IGNITION TESTS.

In test 237 pure coal dust was distributed throughout the explosion zone at the rate of 2 pounds per foot. A very strong explosion

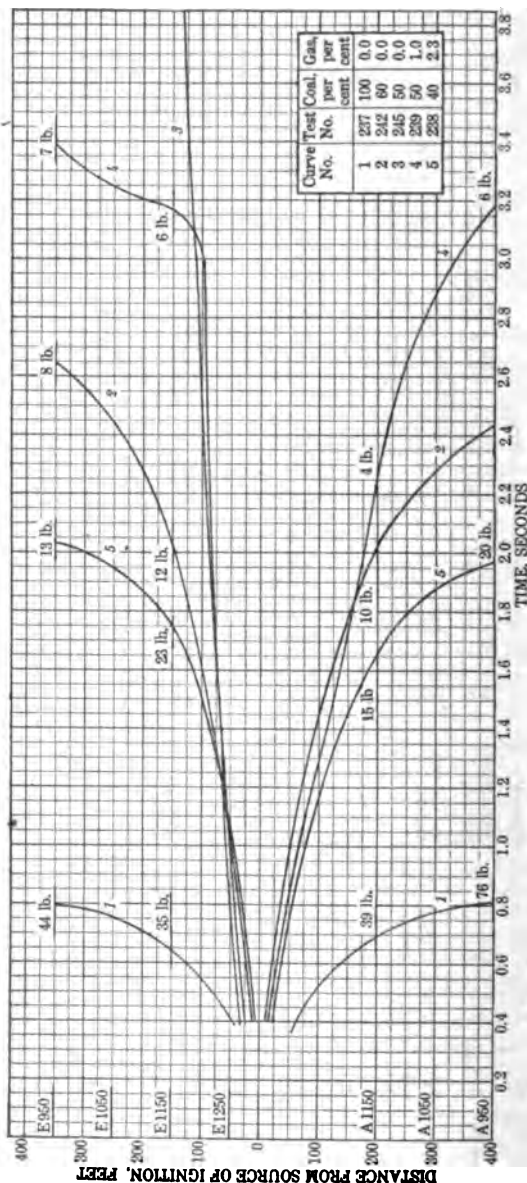


FIGURE 33.—Flame-velocity curves for standard ignition tests of coal dust from the Fire Creek seam (W. Va.). Figure in Italic denotes curve number, figures in roman denote maximum pressure, in pounds per square inch, at that point.

resulted, the pressures at stations E 950 and A 950 being 44 and 76 pounds, respectively. The tin-foil circuits at the 950 stations were broken about 0.8 seconds after the ignition shot was fired. In test 242, on a mixture of 60 per cent coal dust and 40 per cent shale dust, ignition was obtained, but the velocities were much less than in test 237.

In test 245 the shale dust was increased to 50 per cent of the mixture and no ignition was obtained, the flame in both branches of the zone extending only 150 feet from the cannon. In test 239 a mixture of the same percentages—50 coal dust and 50 shale dust—was tested, but with 1.02 per cent natural gas in the air current: a weak explosion resulted, with low pressures.

In test 238 the percentage of shale dust was increased to 60 and the percentage of natural gas in the air to 2.33; the effect of the increased percentage of natural gas offset the increase in the shale percentage, and a strong explosion resulted. In test 240 the percentage

of shale was increased to 70, with 2.12 per cent of natural gas in the air; no ignition resulted, the flame extending only 25 feet from the cannon.

PROPAGATION TESTS.

In test 246 propagation was obtained with a 50 per cent coal dust and 50 per cent shale dust mixture, the velocities being rather high. In test 247, with a 40 per cent coal dust and 60 per cent shale dust mixture, propagation was not obtained. The length of flame in the entry, however, was 250 feet, indicating that a slightly lower percentage of shale would permit propagation.

In test 241 the mixture contained 30 per cent coal dust and 70 per cent shale dust, and there was 1.62 per cent of gas in the air current. Propagation was not obtained under these conditions.

Figure 38 shows the flame velocities in the ignition tests. This chart shows the high velocities attained in the test 237, with pure coal dust, and the relative velocities in test

242 caused by the percentage of shale dust. It can be noted that the velocities in test 239^{4b} are still slower than those in test 242, the increased percentage of shale dust more than offsetting the percentage

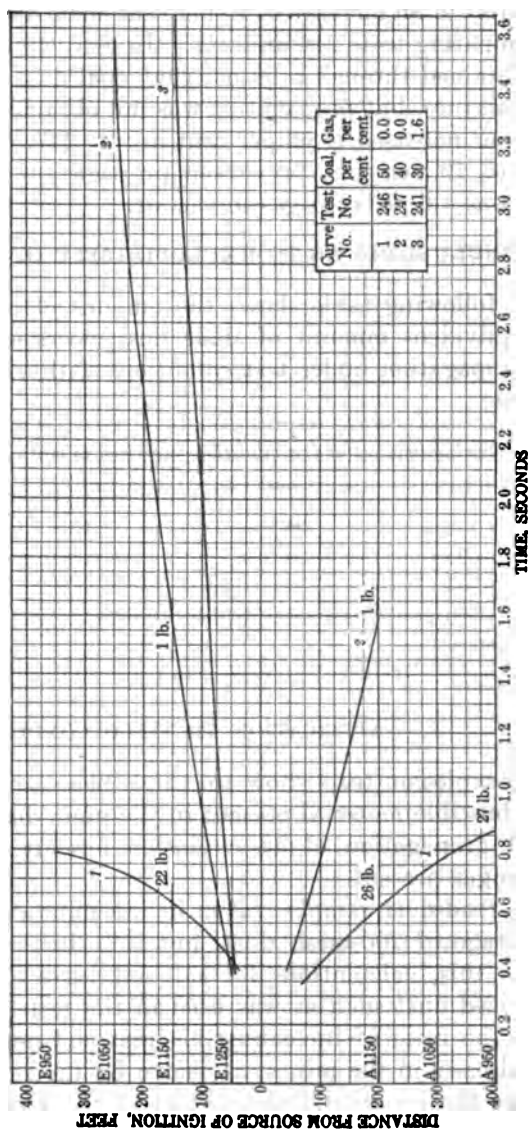


FIGURE 38.—Flame-velocity curves for standard propagation tests of coal dust from the Fire Creek seam (W. Va.). Figure in *italics* denotes curve number, figure in *roman* denotes maximum pressure developed, in pounds per square inch, at that point.

^{4b} The sudden bend in the velocity curve of test 239 is due to delayed fusing of the station foil at E 1150, which fused 0.924 second after the center foil there.

of gas present. The opposite result was obtained in test 238, where the percentage of natural gas present more than offset the increase in the shale dust, as compared with tests 242 and 239, and consequently a more rapid explosion resulted.

Figure 39 shows the flame velocities in the propagation tests. The effect of an increase of 10 per cent shale dust is strikingly evident on comparing tests 246 and 247. In test 246 a very rapid explosion was obtained through a 50 per cent coal dust and 50 per cent shale dust mixture, but propagation was not obtained where the shale content was increased to 60 per cent in test 247. A further increase of shale to 70 per cent prevented propagation in test 241, although there was 1.6 per cent gas in the air.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

The following table shows the amount of total incombustible, or the equivalent amount of shale dust, necessary to prevent ignition and propagation under test conditions with varying amounts of gas present:

Data showing amount of incombustible necessary to make the coal dust nonexplosive.

Item.	Gas.	Incombustible.	Shale dust.
	Per cent.	Per cent.	Per cent.
Nonignition.....	0	55	50
Do.....	1	63	60
Do.....	2	73	70
Nonpropagation.....	0	63	60
Do.....	1.5	73	70

APPLICATION TO FIELD CONDITIONS.

The explosion tests show that it is necessary to have 63 per cent incombustible material present in the mine dust to prevent the continued propagation of an explosion already initiated when there was no gas present.

The road-dust samples taken in the mine do not all show a high percentage of 200-mesh dust, but it is believed that with coal as soft as this, calculations for safe mixtures should be based upon pulverized dust such as was used in the tests. The following table shows the ratio of incombustible material necessary to add to the dust already in the mines, as shown by the samples taken, in order to raise the incombustible content of the resulting mixture to the desired 63 per cent. Should gaseous conditions develop later, this per centage would have to be raised as indicated in the foregoing table.

Additions of incombustible required to render harmless the mine dust in a coal mine working the Fire Creek coal.

Laboratory No. of sample.	Kind of dust.	Incom- bustible present.	Incom- bustible desired.	Ratio of incom- bustible to be added.
		<i>Per cent.</i>	<i>Per cent.</i>	
21514	Road dust..	16.54	63	1.26
21517	do.....	15.97	63	1.27
21519	do.....	35.25	63	.75
21516	do.....	32.65	63	.82
21512	do.....	20.69	63	1.14
21522	do.....	23.69	63	1.06
21518	do.....	24.62	63	1.04
21513	do.....	23.00	63	1.08
21520	do.....	59.32	63	.10
21524	do.....	28.55	63	.93
21523	do.....	23.09	63	1.08
21526	do.....	12.90	63	1.35
21527	do.....	39.20	63	.64
21521	do.....	35.88	63	.73
21515	do.....	12.68	63	1.36
21525	Rib dust....	27.18	63	.97
21529	do.....	21.34	63	1.13

If the watering method of rendering dust nonexplosive is preferred, it is necessary that the mine be kept thoroughly wet at all times, care being taken to wash all dust from timbers and ledges at frequent intervals.

EXPLOSIBILITY TESTS OF COAL DUST FROM UPPER FREEPORT OR E BED, CAMBRIA COUNTY, PA.

GENERAL CHARACTER OF EXPLOSION TESTS.

A series of 12 explosion tests was made on 20-mesh and pulverized dust prepared from a 5-ton sample of run-of-mine coal from a mine in Cambria County, Pa., working in the E, or Upper Freeport, seam. The objects of these tests were to determine the relative explosibility of this coal as compared with coal from other seams and to determine the ignition and propagation limits with the coal dust comparable in incombustible content and in size to that found in this mine. The tests were standard ignition and propagation tests.

CONDITIONS IN MINE WHEN SAMPLE WAS OBTAINED.

Examination was made of the conditions in the mine from which this sample was procured in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane, so that the tests at the experimental mine might approximate the actual mine conditions.

Six standard face samples of the coal were obtained. The analyses of these samples are given in the following table:

Results of analyses of face samples of coal from a mine working the Upper Freeport bed, Cambria County, Pa.

Laboratory No. of sample.	Analysis as received.				Moisture plus ash.	Ratio V V+FC
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
26398	3.03	18.14	71.91	6.92	9.95	20.15
26399	3.54	18.65	72.18	5.63	9.17	20.53
26400	3.45	17.73	72.51	6.31	9.76	19.65
26401	3.80	19.54	71.04	5.82	9.42	21.57
26402	3.08	18.91	70.80	7.21	10.29	21.08
26403	3.39	18.95	71.54	6.12	9.51	20.95

The analysis of a composite sample prepared from the face samples of this semibituminous coal is as follows:

Results of analysis of composite sample.

[Analysis on basis of coal as received.]

Proximate analysis:

Moisture.....per cent..	3.32
Volatile matter.....do....	18.25
Fixed carbon.....do.....	72.03
Ash.....do.....	6.40
Moisture plus ash.....do....	9.72
Ratio of volatile to total combustible.....do.....	20.22

Ultimate analysis:

Hydrogen.....per cent..	4.73
Carbon.....do.....	80.66
Nitrogen.....do.....	1.42
Oxygen.....do.....	5.02
Sulphur.....do.....	1.77
Ash.....do.....	6.40

Two road dust samples and two rib dust samples were obtained. The wet condition of this mine prevented satisfactory sampling of the dust in other places. The analyses and screen tests of these road and rib dusts are as follows:

Results of analyses and screen tests of road and rib dust from a mine working the Upper Freeport bed, Pennsylvania.

Laboratory No. of sample.	Kind of dust.	Analysis as received.				Moisture plus ash.	Ratio V V+FC	Screen test, cumulative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
26405....	Road dust.	6.89	17.88	56.63	18.60	25.49	23.99	11.0	5.0
26408....	do.....	8.64	19.32	62.20	9.84	18.48	23.70	14.5	7.2
26406....	Rib dust.	7.27	17.82	51.89	23.02	30.29	25.56	13.2	7.1
26407....	do.....	8.43	18.75	60.06	12.76	21.19	23.80	8.8	4.0

Ten mine air samples were taken, and the analyses of these showed no methane present in any of them.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

Explosion tests were made with 20-mesh dust and with pulverized dust. The 20-mesh dust was prepared so that 10 per cent thereof would pass a 200-mesh screen, this size being selected because none of the samples from the mine showed more than this amount of dust through 200-mesh.

Two ignition tests were made with pulverized dust and four with 20-mesh dust. Two propagation tests were made with pulverized dust and four with 20-mesh dust. One per cent gas was used in one ignition test on pulverized dust and in one propagation test on 20-mesh dust.

The average analyses of the 20-mesh coal dust (10 per cent through 200-mesh) and of the pulverized coal dust used in these tests were as follows:

Average composition of the coal dusts used.

	20-mesh dust.	Pulverized dust.
Moisture.....per cent....	1.91	1.67
Volatile matter.....do....	18.37	18.96
Fixed carbon.....do....	69.70	72.66
Ash.....do....	10.02	6.71
	100.00	100.00
Ratio of volatile to total combustible.....	20.87	20.70

The noticeably lower ash content of the pulverized coal is due to part of the harder impurities becoming separated from the coal in the process of grinding and screening.

The average analysis of the shale dust used in these tests showed a moisture content of 1.53 per cent, and of total incombustible, 99.52 per cent.

Average sizing tests of the coal dusts and the shale dust were as follows:

Results of average sizing tests of the coal dusts and the shale dust.

Material.	Through 20-mesh.	Through 48-mesh.	Through 100-mesh.	Through 200-mesh.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Pulverized coal dust.....			99.4	84.6
20-mesh coal dust, 10 per cent through 200-mesh.....	94.7	56.2	25.5	10.0
Pulverized shale dust.....			100.0	98.4
20-mesh shale dust.....	88.0	63.1	37.9	27.4

The principal data in connection with the explosion tests on this coal are presented in Table 35.

TABLE 35.—Results of standard tests of coal dust from the E or Upper Freeport bed, Indiana County, Pa.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Sizes of coal dust used: 20-mesh, of which 10 per cent would pass 200-mesh, and pulverized. Size of pit-shale dust used: 20-mesh and pulverized. In the ignition tests, in which mixed dust was used, the rate of mixed-dust distribution in the first 30 feet was twice that used in the rest of the zone and given in the table. The mixed-dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 950, 350 feet; and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Size of dust used.	Ratio of coal dust to shale dust in mixture.	Mixed dust.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.					Length of flame in mixed-dust zone.	Remarks.
				Calculated combustible content.	Rate of loading.	Total loading.		Station 1150.	Station 950.	Foil at station 1150.	Foil at station 1250.	Foil at station 1050.	Foil at station 950.	Foil at station 850.		
				Per cent.	Lbs. per ft.	Lbs.	Per cent.	Lbs. per sq. ft.	Station 1150.	Foil at station 1150.	Foil at station 1250.	Foil at station 1050.	Foil at station 950.	Foil at station 850.		
356	Dec. 8, 1916	20-mesh	(e)	11.9	2.00	1,400	0.0	40	45	190	0.952	704	1,961	1,120	(b)	Ignition obtained.
358	Dec. 13, 1916	do.	(e)	11.9	2.00	1,400	0	40	94	376	683	775	817	4,348	(b)	Do.
365	Jan. 3, 1917	do.	70:30	38.4	1.43	1,071	0	13	14	193	1.216	184	699	1,902	(e)	Do.
367	Jan. 8, 1917	do.	60:40	47.2	1.67	1,250	0	1	1	.....	.....	.....	.....	.....	75 125	Ignition not obtained.
368	Jan. 9, 1917	Pulverized.	80:40	45.0	1.67	1,250	0	9	11	807	98	238	433	2,468	(e)	Ignition obtained.
370	Jan. 12, 1917	do.	50:50	54.2	2.00	1,500	.95	16	18	1,730	402	284	2,331	2,941	(e)	Do.

PROPAGATION TESTS.

360	Dec. 18, 1916	20-mesh	60:40	47.2	1.67	1,083	0.0	{Entry..... Air course.	15 13	12 18	0.421	357	0.701 .771	280 388	1.135 1.029	985 621	1.242 1.180	{(b) (b)}	Propagation obtained.
362	Dec. 22, 1916	do....	50:50	56.0	2.00	1,300	.0	{Entry..... Air course.	9 9	9 10	.241	243	.653 .671	248 269	1.057 1.045	500 566	1.257 1.250	{(b) (b)}	Do.
364	Dec. 28, 1916	do....	40:60	65.8	2.50	1,025	.0	{Entry..... Air course.	1 1	1 1	.417	118	1.264 1.257	37 94	2.947 2.806	..... .....	..... .....	{175 250	Propagation not obtained.
366	Jan. 5, 1917	do....	40:60	65.8	2.50	1,025	.95	{Entry..... Air course.	9 7	 9	.419	495	.649 .668	238 253	1.070 1.068	398 610	1.331 1.263	{(b) (b)}	Propagation obtained.
361	Dec. 20, 1916	{Pulver- ised.	50:50	54.2	2.00	1,300	.0	{Entry..... Air course.	12 11	9 13	.480	338	.776 .757	361 317	1.063 1.072	538 594	1.239 1.263	{(b) (b)}	Do.
363	Dec. 27, 1916	do....	40:60	63.4	2.50	1,025	.0	{Entry..... Air course.	4 3	3 2	.413	206	.837 .808	121 171	1.065 1.394	61 132	2.310 2.162	{(b) (b)}	Do.

Flame velocity and pressure curves of this test are shown in figure 61.

Flame extended through zones.

All coal.

DISCUSSION OF RESULTS.

IGNITION TESTS.

With pulverized dust an ignition was obtained in test 368 in a mixture containing 60 per cent of coal dust and 40 per cent of shale dust, with no gas in the ventilating current, also in test 370 in a mixture containing 50 per cent of coal dust and 50 per cent of shale dust, with 1 per cent of gas in the ventilating current.

With a mixture of 70 per cent 20-mesh coal dust and 30 per cent 20-mesh shale dust, with no gas, an ignition was obtained in test 365; but ignition was not obtained in test 367 when the coal dust was reduced to 60 per cent of the mixture.

PROPAGATION TESTS.

Propagation was obtained in test 362 with a mixture of 50 per cent 20-mesh coal dust and 50 per cent shale dust, with no gas in the ventilating current. With 40 per cent coal dust and 60 per cent shale dust, propagation was not obtained in test 364, with no gas in the ventilating current, but was obtained in test 366 with 1 per cent of gas present.

Propagation was obtained in test 363 with a mixture of 40 per cent of pulverized coal dust and 60 per cent pulverized shale dust. The low pressures developed in this test indicate that a slightly greater percentage of shale would prevent propagation.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

The explosion tests show that under the conditions of test, with dry 20-mesh dust, of which 10 per cent would pass 200-mesh, it is necessary to have 48 per cent of incombustible material present to prevent the initiation of an explosion by the standard blown-out shot and 65 per cent of incombustible material present to prevent the continued propagation of such an explosion, there being no gas present in either case. These percentages of incombustible are equivalent to the presence of 40 per cent and 60 per cent of admixed inert material, respectively.

APPLICATION TO FIELD CONDITIONS.

As 65 per cent of incombustible material is required to prevent the propagation of an explosion through the dust of this mine, and none of the four samples of mine dust taken contained this amount, some inert dust would have to be added to produce a safe condition. This mine was very wet and the four samples contained considerable moisture, the lowest moisture content being about 7 per cent. Furthermore, the wet condition of the mine prevented the taking of other samples. With considerable amounts of water present the amount of total incombustible material (moisture and ash) may be reduced, as shown by a series of tests reported in Chapter VIII. Great caution should be observed in using this fact, however; also it is best to have a large excess of incombustible material present.

The conclusions may be summarized as follows: With "dry" dust (containing 1 or 2 per cent of moisture) of the size found in the mine, it is necessary to have 65 per cent of moisture and ash to prevent the propagation of an explosion in the absence of gas. If the dust is to be rendered inert by wetting, all the dust must be wet all the time and wet enough to prevent its being blown into the air by an advancing explosion. Watering should be done frequently and all fresh dust washed down from the timbers and ledges.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE BECKLEY BED, NEW RIVER DISTRICT, WEST VIRGINIA.

GENERAL CHARACTER OF TESTS.

A series of explosion tests was made on pulverized dusts prepared from a sample of run-of-mine coal obtained from a mine in West Virginia working the Beckley seam. The object of this series was to determine the percentage of shale dust necessary to prevent ignition and to prevent propagation of an explosion under standard test conditions, both with and without gas in the ventilating current. These tests were made before the methods of testing 20-mesh dust had been developed; consequently all tests were made with pulverized dust.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

The Beckley bed is one of the New River beds containing semibituminous coal, and the mines not infrequently encounter gas. This condition, with the friable, dust making coal, is productive of explosion hazards that necessitate great care in mining.

The mine had been examined previous to the taking of the large coal sample, the purpose being to obtain information about some special conditions existing at that time. Samples of the coal, the road and rib dusts, and the mine air were taken at that time. Although these were not taken with the experimental-mine tests particularly in view, they gave valuable information in connection with the testing work.

Five standard face samples were obtained, the analyses being as follows:

Results of analyses of face samples of coal from a mine working the Beckley bed, West Virginia.

Laboratory No. of sample.	Coal as received.				Moisture and ash.	Ratio V V+FC
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
19778	1.68	18.61	72.55	7.16	8.84	20.41
19777	1.83	17.97	74.38	5.72	7.55	19.47
19776	1.69	18.13	72.12	8.06	9.75	20.09
19775	1.59	19.00	73.61	5.80	7.39	20.52
19774	1.63	18.76	74.67	4.94	6.57	20.08

The results of an analysis of a composite of these face samples was as follows:

Results of analyses of composite sample.

[Analysis made on basis of coal "as received."]

Proximate analysis:

Moisture.....	per cent..	1.82
Volatile matter.....	do....	18.39
Fixed carbon.....	do....	73.32
Ash.....	do....	6.47
Moisture plus ash.....	do....	8.29
Ratio of volatile to total com- bustible.....		20.05

Ultimate analysis:

Hydrogen.....	per cent..	4.41
Carbon.....	do....	82.67
Nitrogen.....	do....	1.47
Oxygen.....	do....	4.19
Sulphur.....	do....	.79
Ash.....	do....	6.47

Thirteen samples of road dust and one of rib dust were obtained. the analyses being given in the following table:

Results of analyses of road dust and rib dust from a coal mine working the Beckley bed, West Virginia.

Labora- tory No. of sample.	Kind of dust.	Analysis as received.				Moisture plus ash.	Ratio V V + FC
		Moisture.	Volatile matter.	Fixed carbon.	Ash.		
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
19743	Road dust.	1.35	15.33	48.99	34.33	35.68	23.83
19744	...do.....	.85	12.03	37.56	49.56	50.41	24.26
19745	...do.....	1.14	17.53	66.06	15.27	16.41	20.97
19746	...do.....	2.35	16.93	68.47	11.25	13.60	19.60
19748	...do.....	5.56	16.18	70.65	7.61	13.17	18.63
19753	...do.....	1.84	17.40	74.31	6.45	8.29	18.98
19754	...do.....	2.80	16.39	74.79	6.02	8.82	17.97
19756	...do.....	2.08	16.72	66.25	15.85	17.93	20.37
19757	...do.....	1.90	17.33	71.73	9.04	10.94	19.47
19758	...do.....	4.18	15.46	69.82	10.54	14.72	18.12
19763	...do.....	.74	12.16	45.80	41.30	42.04	20.98
19764	...do.....	1.30	15.93	70.77	12.00	13.30	18.37
19765	...do.....	1.96	13.26	71.38	13.41	15.36	15.66
19747	Rib dust..	.65	17.55	75.29	6.51	7.16	18.90

The content of moisture and ash in the road dusts ranged from 8.29 to 50.41 per cent. The moisture content was low in all the samples; in only one instance was it more than 5 per cent.

A number of mine-air samples were collected, of which the following are typical:

Results of analyses of mine-air samples from a coal mine working the Beckley bed, West Virginia.

Labora- tory No. of sample.	Ventilating conditions at place of sampling.	Methane in sample.
		<i>Per cent.</i>
5179	Sample taken in still air.....	1.17
5178	...do.....	.29
5441	Sample collected in main return.....	.43
5442	...do.....	.25

It was evident that considerable methane was being liberated in the mine and that the methane would rise to dangerous proportions locally in the absence of ventilation.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

This sample of coal was tested prior to adoption of explosion testing with coarse coal dust; therefore pulverized dust was used. Eleven tests were made, some without gas and some with natural gas in the air current in the early summer of 1914 before the test zone had been cemented. As the mine was damp, it was very difficult to clean between tests, and the results obtained indicated a lower degree of explosibility than would otherwise have been shown. About a year later, after the explosion zone had been concreted, another sample of coal was procured from the company and 10 tests (Nos. 201 to 210) were made with this sample. The average analyses of the coal dust in the later series of tests was as follows:

Results of average analyses of the coal dust.

Moisture.....	per cent..	0. 85
Volatile matter.....	do....	18. 20
Fixed carbon.....	do....	72. 37
Ash.....	do....	8. 57
		100. 00
Moisture plus ash.....	do....	9. 43
Ratio of volatile to total combustible.....		20. 09

The average sizing tests of the coal dust showed that 99.9 per cent would pass through 100 mesh, 95.1 per cent through 200 mesh (screen A), and 92.2 per cent through 240 mesh.

The shale used to mix with the coal dust in these tests was pulverized pit shale, of which the average screen tests showed that 100 per cent would pass through 100 mesh, 97 per cent through 200 mesh (screen A), and 95 per cent through 240 mesh.

The tests of this series, including one test of the first series (No. 131), comprised three ignition tests without gas and five with gas present; and two propagation tests without gas and one with gas present. The results of the tests are presented in Table 36.

TABLE 36.—Results of standard tests of coal dust from the Beckley bed, West Virginia.

Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust used: Pulverized. Size of pit-shale dust used: Pulverized. In the ignition tests the mixed-dust zones extended from stations E 1260 to E 960, 350 feet, and from stations E 1260 to A 960, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (Pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 960, 300 feet, and from stations E 1250 to A 960, 350 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Ratio of coal dust to shale mixture.	Mixed dust			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
			Calculated incom-bustible content.	Rate of load-ing.	Total load-ing.		Station 1150.	Station 950.	Fall at station 1250.	Ve-locity.	Fall at station 1150.	Ve-locity.	Fall at station 1050.	Ve-locity.	Fall at station 950.	
201	1915. Apr. 13	80:20	Per cent. 26.6	Lbs. per ft. 2.50	Lbs. 1,750	Natural gas used. 0.0	Lbs. per sq. ft. 23	Lbs. per sq. ft. 33	Sec. onds. 0.921	Ft. per sec. 441	Sec. onds. 1.185	Ft. per sec. 1,120	Sec. onds. 1.235	Ft. per sec. 1,468	Sec. onds. 1.594	Ignition obtained.
202	Apr. 17	70:30	37.6	2.86	2,000	.0	11	10	1.119	179	1.678	437	1.907	877	2.021	Do.
203	Apr. 21	60:40	45.2	3.23	2,353	.0	0	0	0	0	1.567	538	1.773	1,112	1.863	Ignition not obtained.
131	June 27	60:40	41.6	3.33	2,383	.87	0	0	2.185	0	0	0	0	0	0	Ignition not obtained. Roof shale dust used in this test.
204	1914. Apr. 21	60:40	45.1	3.23	2,333	1.00	7	9	2.070	308	2.369	149	3.072	1,112	3.161	Ignition obtained.
208	Apr. 29	50:50	54.1	4.00	2,900	2.38	18	6	.036	0	2.535	347	2.812	503	3.011	Do.
209	May 3	40:60	63.6	5.00	3,800	2.25	75	53	1.188	122	3.002	87	4.147	255	4.558	Do.
210	May 4	30:70	72.7	6.00	3,600	2.10	0	1	0	0	2.747	133	3.501	0	3.894	Ignition not obtained.

PROPAGATION TESTS.

[illegible]

Flame extended through zones. Probably the foil at A 950 was broken, and foil at A 1150, by violence ahead of flame.

b Roof shale.

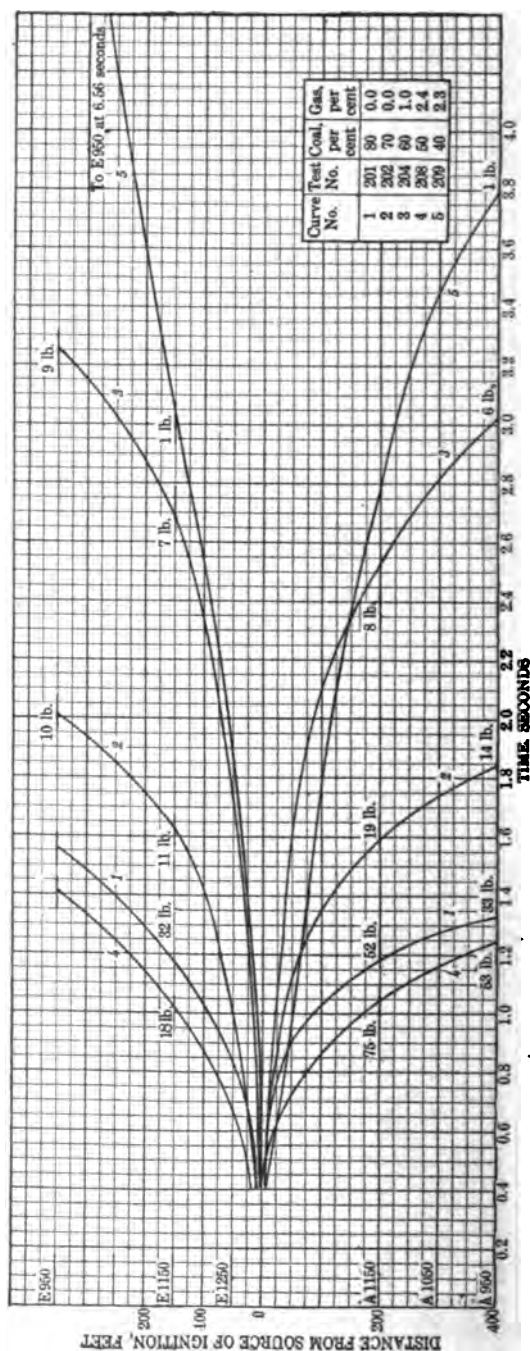


FIGURE 40.—Flame-velocity curves for standard ignition tests of coal dust from the Beckley seam (W. Va.). Figure in *italics* denotes curve number; figures in roman denote pressure in pounds per square inch developed at that point.

DISCUSSION OF RESULTS.

IGNITION TESTS.

In test 201 a strong ignition was obtained with a mixture of 80 per cent coal dust and 20 per cent shale dust, a maximum pressure of 52 pounds being recorded at station A 1150. In test 202 ignition was obtained with 70 per cent coal dust and 30 per cent shale dust; the velocities in this test, however, were much less than in test 201, as shown by the flame velocity curves in figure 40. In test 203 the percentage of coal dust was reduced from 70 to 60 and ignition was not obtained, the flame extending only 150 feet from the cannon into the air course.

In test 131 ignition was not obtained with a mixture of 60 per cent coal dust and 40 per cent pulverized roof shale dust, with 0.87 per cent natural gas in the air current. The shale dust used in this test contained 9 to 10 per cent combustible material, and a mixture containing this shale would be more explosive than one with pit shale. On the other hand, this test was made when the mine was damp.

In test 204 ignition was obtained with a mixture of 60 per cent coal dust and 40 per cent shale dust with 1 per cent of natural gas in the air current, but the velocities of the flame were not high. A mixture of 50 per cent coal dust and 50 per cent shale dust would probably not give ignition with 1 per cent of natural gas in the air current.

In test 208 a very strong ignition was obtained through a mixture of 50 per cent coal dust and 50 per cent shale dust, with 2.38 per cent of natural gas. The velocities in this test were higher than those in any other test in the ignition series, as shown in figure 40 (p. 314). Judging from the high pressures obtained—75 pounds at station A 1150 and 53 pounds at station A 950—ignition would have been obtained with a much lower percentage of gas. In test 209 ignition was obtained with a mixture of 40 per cent coal dust and 60 per cent shale dust, with 2.25 per cent natural gas in the air current. The comparison of curves 5 and 4, figure 40, shows the decided decrease in velocities due to the increase in the percentage of shale dust in this test as compared with test 208. In test 210 ignition was not obtained through a mixture of 30 per cent coal dust and 70 per cent shale dust, with 2.10 per cent natural gas in the air current.

PROPAGATION TESTS.

In test 205 propagation was not obtained with a mixture of 50 per cent coal dust and 50 per cent shale dust, with no gas present, the flame extending only 150 feet beyond the ignition zone. In test 206 propagation was obtained with a mixture of 60 per cent coal dust

and 40 per cent shale dust, pressures of 9 to 17 pounds being recorded. A comparison of curves 1 and 2, figure 41, shows the increased

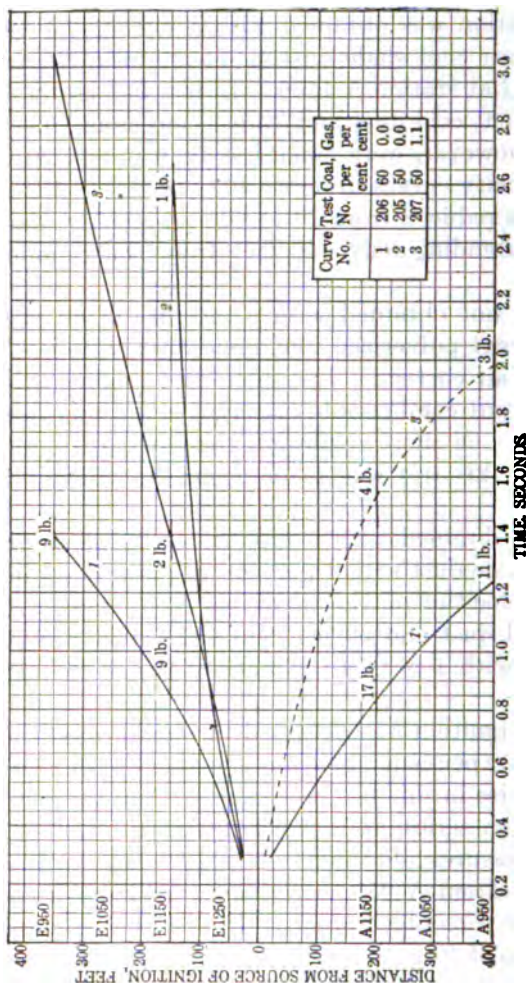


FIGURE 41.—Flame-velocity curves for standard propagation tests of coal dust from the Beckley seam (W. Va.). Figure in *italic* denotes curve number; figure in roman denotes pressure in pounds per square inch developed at that point.

velocity developed in this test over that of test 205.

In test 207 propagation was obtained with the same mixture as was used in test 205—that is, 50 per cent coal dust and 50 per cent shale dust, with 1.15 per cent natural gas in the air current. The pressures were very light and the velocity low in this test, three seconds being required for the flame to reach the end of the zone at station E 950, indicating that a mixture having 60 per cent shale dust would not propagate.^{44c}

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

The following table gives the percentages of incombustible

material or the equivalent percentages of inert dust that must be present to prevent ignition and to prevent propagation through mixtures with the pulverized Beckley coal dust under test conditions:

Content of inert material needed to make mixtures with the Beckley coal dust nonexplosive

	Gas present.	Incombustible.	Inert dust.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Nonignition.....	0	45	60
Do.....	1	54	50
Do.....	2	73	70
Nonpropagation.....	0	54	50
Do.....	1	63	60

^{44c} A later conclusion is that the foil at A950 was probably broken by violence before arrival of flame and dotted line of velocity curve (3).

APPLICATION TO FIELD CONDITIONS.

As the air samples taken in the mine indicate that considerable methane was present, it would be advisable to maintain the percentage of incombustible material in the mine dust of the entries at 63 per cent, which corresponds to the mixture of 60 per cent shale dust and 40 per cent coal dust. The tests have indicated that such a mixture would not propagate in any explosion under the test conditions with 1 per cent of natural gas in the air current.

The tests were made with pulverized dust, which gives an added factor of safety, because the mine dusts are not as fine.

The following table shows the ratio of incombustible material that it would be necessary to add to the dust already in the mine as shown by the samples in order to raise the incombustible content to the desired 63 per cent.

Additions of incombustible needed to make the mine dusts nonexplosive.

Laboratory No. of sample.	Kind of dust.	Incombustible present.	Incombustible desired.	Ratio of incombustible to be added.
		<i>Per cent.</i>	<i>Per cent.</i>	
19743	Road dust.	35.68	63	0.74
19744	do.....	62.41	63	.014
19745	do.....	26.41	63	.99
19746	do.....	24.00	63	1.05
19748	do.....	13.17	63	1.35
19754	do.....	8.82	63	1.46
19756	do.....	17.63	63	1.22
19757	do.....	10.94	63	1.41
19763	do.....	54.04	63	.24
19764	do.....	13.30	63	1.34
19765	Rib dust..	15.36	63	1.29

If the watering method is relied on to keep the dust inert, watering should be done at frequent intervals and all dust should be washed down from the timbers and ledges and thoroughly wetted.

EXPLOSIBILITY TESTS OF COAL DUST FROM THE LOWER KITTANNING BED, CAMBRIA COUNTY, PA.

A series of seven explosion tests was made on pulverized dust prepared from a 5-ton sample of coal obtained from a mine in central Pennsylvania working the Lower Kittanning seam. The object of this series was to determine the percentages of shale necessary to prevent ignition and prevent propagation of an explosion under standard test conditions both with and without gas in the ventilating current. The coal was semibituminous and low volatile, of naval grade.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

Investigation was made of the condition of this mine in order to obtain information as to the composition of the coal, the fineness and purity of the road dusts, and the presence of methane so that the tests at the experimental mine might approximate the mine conditions.

Four standard face samples were obtained, the analyses of which are given in the following table:

Results of analyses of face samples of coal from a mine working the Lower Kittanning bed, Pennsylvania.

Laboratory No. of sample.	Analysis (coal "as received").				Moisture plus ash.	Ratio V V+FC
	Moisture.	Volatile matter.	Fixed carbon.	Ash.		
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
25717	3.35	15.36	76.27	5.02	8.37	16.76
25718	2.38	15.46	76.94	5.22	7.60	16.73
25719	2.89	15.58	75.07	6.46	9.35	17.18
25720	3.52	15.24	73.45	7.79	11.31	17.19

The analysis of a composite of these samples was as follows:

Results of analysis of composite sample.

[Analysis on basis of coal "as received."]

Proximate analysis:

Moisture.....per cent..	3.06
Volatile matter.....do....	15.35
Fixed carbon.....do....	75.45
Ash.....do....	6.14
Moisture plus ash.....do....	9.20
Ratio of volatile to total com- bustible.....do....	16.91

Ultimate analysis:

Hydrogen.....per cent..	4.40
Carbon.....do....	81.72
Nitrogen.....do....	1.31
Oxygen.....do....	5.41
Sulphur.....do....	1.02
Ash.....do....	6.14

Four road dust and three rib dust samples were obtained, the analyses and screen tests of which are given in the following table:

Composition and fineness of road and rib dusts from a coal mine working the Lower Kittanning bed, Pennsylvania.

Laboratory No. of sample.	Kind of dust.	Analysis ("as received").				Moisture plus ash.	Ratio V V+FC	Screen test; cumu- lative percentage through—	
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
25723....	Road dust.	3.09	12.16	51.59	33.16	36.25	19.08	21.0	10.7
25724....	do.....	3.67	7.41	30.37	58.56	62.22	19.81	19.1	9.5
25725....	do.....	9.30	11.02	47.63	32.05	41.35	18.79	10.4	6.0
25736....	do.....	3.74	14.16	65.21	16.89	20.63	17.84	53.3	14.5
25727....	Rib dust.	6.46	13.36	52.86	27.32	33.78	20.17	10.3	3.4
25728....	do.....	6.66	12.68	49.67	30.99	37.65	20.34	10.6	5.0
25729....	do.....	6.17	14.98	67.51	11.34	17.51	18.17	18.9	5.3

A number of mine air samples were obtained, none of which contained as much as 0.1 per cent methane.

DETAILS OF EXPLOSION TESTS.

PROCEDURE AND RESULTS.

This sample was obtained before any tests had been made in the experimental mine on coarse sizes of coal dust; hence all the tests of this coal were with pulverized dust. Four ignition tests were made without gas and one ignition test was made with gas present. Three propagation tests were made, without gas in the ventilating current. The average analysis and fineness of the Lower Kittanning coal dust as prepared for the various tests was as follows:

Average composition and fineness of the coal dust as prepared for test.

Analysis:	Per cent.
Moisture.....	0.92
Volatile matter.....	15.98
Fixed carbon.....	75.28
Ash.....	7.82
	100.00
Fineness:	
Through 100-mesh.....	100.00
Through 200-mesh (screen A).....	94.4
Through 240-mesh.....	87.8

Pulverized pit-shale dust was used in these tests. This shale dust averages more than 99 per cent incombustible material and more than 96 per cent through 200-mesh.

The results of the tests are tabulated in Table 37.

TABLE 37.—Results of standard tests of coal dust from the Lower Kittanning bed, Pennsylvania.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Size of coal dust: Pulverized. Size of pit-shale dust used: Pulverized. In the ignition tests the mixed-dust zones extended from stations E 1300 to E 950, 330 feet; and from stations E 1250 to A 950, 330 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1250 to E 950, 300 feet; and from stations E 1250 to A 950, 330 feet; total length, 650 feet.]

IGNITION TESTS.

Test No.	Date.	Ratio of coal dust to shale dust in mixture.	Mixed dust			Natural gas used.	Records obtained in entry or in air course.	Maximum pressure.		Time of tin-fall rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
			Calculated combustible content.	Rate of loading.	Total loading.			Station 1150.	Station 950.	Fall at station 1250.	Ve-locity.	Fall at station 1150.	Ve-locity.	Fall at station 1050.	Ve-locity.			Fall at station 950.
			Per cent.	Lbs. per ft.	Lbs.	Per cent.		Lbs. per sq. in.	Lbs. per sq. in.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	
189c.	1915. Mar. 16..	(a)	9.1	2.00	1,400	0.0	Entry..... (Air course.	16 45	23 67	0.503	224	0.950	1,051	1.047	1,960	1.086	Ignition obtained.
195.	Mar. 22..	80:20	26.6	2.50	1,750	.0	Entry..... (Air course.	12 10	11	.832	61	2.473	394	2.728	592	2.897	Do.
193.	Mar. 23..	70:30	36.0	2.86	2,000	.0	Entry..... (Air course.	0 0	0 0	.....	.....	.....	.....	.....	.....	.....	Ignition not obtained.
192.	Mar. 22..	60:40	45.1	3.33	2,333	.0	Entry..... (Air course.	0 0	0 0	.....	.....	.....	.....	.....	.....	.....	Do.
194.	Mar. 24..	70:30	36.0	2.86	2,000	1.45	Entry..... (Air course.	24 33	.....	1.310	640	1.464	520	1.656	1,298	1.733	Ignition obtained.

PROPAGATION TESTS.

	1915. Mar. 18..	70:30	36.0	2.86	1,857	0.0	{Entry..... Air course.	16 18	 16	0.432	260	0.817 .837	552 602	0.968 983	720 1,516	{b) 1,059	Propagation obtained.
190.	1915. Mar. 18..	70:30	36.0	2.86	1,857	0.0	{Entry..... Air course.	16 18	 16	0.432	260	0.817 .837	552 602	0.968 983	720 1,516	{b) 1,059	Propagation obtained.
197.	Apr. 6..	60:40	45.4	3.33	2,167	.0	{Entry..... Air course.	.....	.....	.443	149	1.115 1.300	160 699	1.740 1.443	108 685	{b) 1,589	Do.
196.	Apr. 2..	50:50	54.2	4.00	2,600	.0	{Entry..... Air course.	1 1	0 0	.657	47	2.798 3.667	.....	.....	.....	159 175	Propagation not ob- tained.

* All coal.

* Flame extended through zone.

* Flame velocity and pressure curves of this test are shown in figure 92.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE COAL DUST.

Ignition may not be obtained with a mixture of 70 per cent coal dust and 30 per cent shale dust without gas present, but may be obtained with this mixture with 1.5 per cent of natural gas in the ventilating current.

When no gas is present, a mixture of 50 per cent coal dust and 50 per cent shale dust will not permit propagation under conditions as in the experimental mine.

APPLICATION TO FIELD CONDITIONS.

The seven samples of the road and rib dust show a very low percentage of 200-mesh dust; only one sample had a content appreciably higher than 10 per cent.

The later tests on coarse sizes of Pittsburgh coal dust show that with coal dust of which only 10 per cent will pass through 200-mesh much less shale dust was required to prevent propagation than with pulverized dust. As 50 per cent shale dust will prevent propagation in mixtures with the pulverized coal

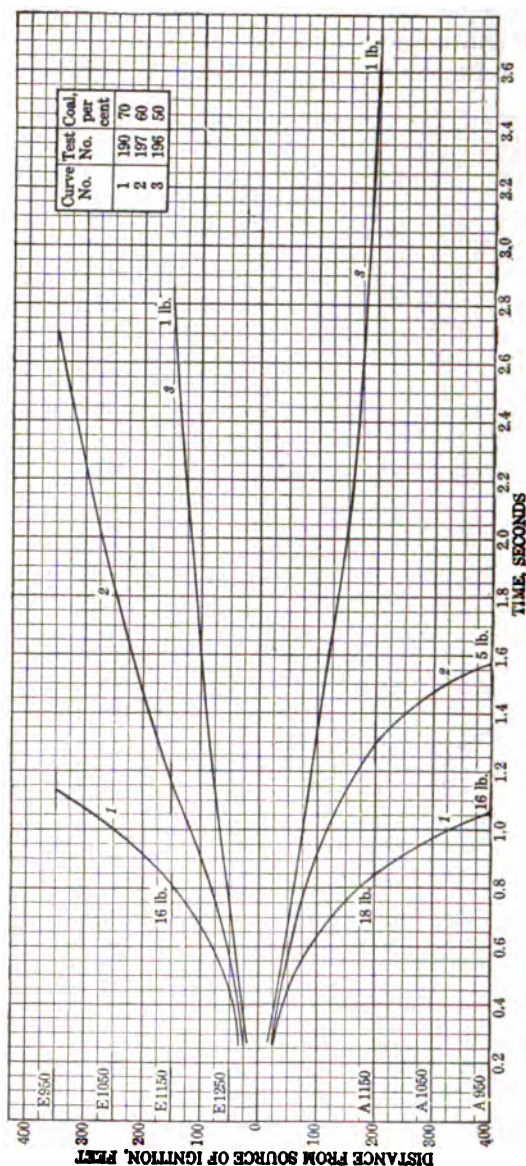


FIGURE 43.—Flame-velocity curves for standard propagation tests of coal dust from the Lower Kittanning seam (Pa.). Figure in *italics* denotes number of curve; figures in *roman* denote pressure developed in pounds per square inch at that point.

dust, 40 per cent shale dust would probably prevent propagation with the sizes of dust as indicated by the road and rib samples. A mixture of 60 per cent Kittanning coal dust and 40 per cent shale dust contains 45 per cent incombustible matter.

The following table shows the amount of incombustible material that would have to be added to the dust already in the mine, as shown by the road and rib samples, in order to raise the incombustible content to the desired content of 45 per cent. The amounts are smaller than are usually required to make road dusts inert.

Additions of inert dust required to render harmless the mine dust in a mine working the Lower Kittanning bed, Pennsylvania.

Laboratory No. of sample.	Incombustible present.	Incombustible desired.	Ratio of incombustible to be added.
	<i>Per cent.</i>	<i>Per cent.</i>	
25723	36.25	45	0.16
25724	62.22	45	(a)
25725	41.35	45	.066
25726	20.63	45	.44
25727	33.78	45	.20
25728	37.65	45	.13
25729	17.51	45	.50

a None needed.

Therefore in order that the mine dust be nonexplosive in the absence of gas the analysis of that portion of the dust passing through a 20-mesh screen should show at least 45 per cent of ash plus moisture, or, if dependence is placed on wetting for rendering the coal dust inert, it should be kept thoroughly wetted by frequent washings in such a manner as to remove all fine dust from the timbers and ledges.

EXPLOSIBILITY TESTS ON LYKENS VALLEY ANTHRACITE DUST, PENNSYLVANIA.

GENERAL STATEMENT.

An extended series of tests was made on Lykens Valley anthracite to determine under what conditions, if any, the dust might be explosive. The attention of the bureau's engineers was first drawn to the possibility of this dust being explosive by a report that an explosion of dust had occurred in an old breaker which was being torn down. The cause of the dust being ignited was supposed to have been the firing of a charge of dynamite to facilitate dismantling some machinery in the breaker. Samples of the coal were shipped to the Pittsburgh station and were used in a series of preliminary explosion tests in a 100-foot steel gallery. These tests indicated that the dust might be explosive under favorable conditions, as the dust had a higher volatile content than the anthracite of other districts. The tests were made on dust ground at Pittsburgh from the lump coal which had been shipped. It was thought desirable to visit the mine and take samples of road and rib dust. Analyses and sizing tests of these dust samples would show whether or not the mine dust was as dangerous as that ground from lump coal.

CONDITIONS IN ANTHRACITE MINE SAMPLED.

Samples were gathered from a number of points in the mine. The results of the analyses and screen tests are as follows:

Results of analyses and screen tests of the road and rib dusts from a mine working the Lykens Valley anthracite.

Laboratory No. of sample.	Kind of dust.	Analyses as received.				Moisture plus ash.	Ratio V V+FC	Percentage of 20-mesh dust through—		
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.	240-mesh screen.
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.				
19535...	Road dust.....	1.31	8.51	74.16	16.02	17.33	10.29	.....	.....	.....
19534.....	do.....	1.27	9.81	40.68	48.24	49.51	19.44	.....	.....	.....
19539.....	do.....	1.66	10.57	67.72	20.05	21.71	13.50	92.3	80.4	80.0
19544.....	do.....	2.23	10.33	63.96	23.48	25.71	13.91	72.8	62.8	61.3
19543.....	Road and rib dust..	1.00	10.06	77.56	11.38	12.38	11.48	27.6	14.6	10.7
19546.....	do.....	2.56	10.73	48.91	37.80	40.36	17.99	42.2	26.2	23.3
19536.....	Rib dust.....	1.06	9.49	50.53	38.92	39.98	15.81	71.9	57.0	54.4
19538.....	do.....	1.88	10.35	69.15	18.62	20.50	13.02	99.7	94.3	91.9
19540.....	do.....	2.09	10.23	68.56	19.12	21.21	12.99	93.8	88.9	84.0
19541.....	do.....	1.01	9.52	45.68	43.79	44.80	17.25	83.5	68.1	58.2
19542.....	do.....	2.09	9.86	75.13	12.92	15.01	11.60	49.5	35.9	34.5
19537.....	Dust from timbers..	1.51	9.01	78.16	11.32	12.83	10.34	.....	.....	.....
19545.....	do.....	1.12	9.41	67.21	22.26	23.38	12.29	62.9	48.7	47.1
19547.....	do.....	1.80	9.66	76.67	11.87	23.67	11.19	97.9	81.6	74.2

If samples 19546, 19536, 19541, and 19534 be excluded the incombustible content varies from 12.38 to 25.71 per cent; these four samples have a much higher content of incombustible, ranging from 39.98 to 49.51 per cent. The moisture content of all the samples was low.

The screen tests show a higher percentage of 200-mesh dust, ranging from 35.9 per cent to 94.3 per cent, except for two samples which showed only 14.6 and 26.2 per cent, respectively.

Additional large samples of mine dust were gathered at this time by the mine management and were sent to Pittsburgh for the purpose of making further gallery tests as a check on the results of the preliminary tests, which had been made with the dust ground from lump coal. The tests made with these dust samples gave results similar to those obtained in the previous tests.

EXPLOSION TESTS IN EXPERIMENTAL MINE.

PROCEDURE AND RESULTS.

The dust used in the gallery tests had been so pulverized that usually more than 90 per cent would pass through a 200-mesh screen; the ash content varied roughly from 8 to 14 per cent. In general, therefore, the dust used in these experimental tests was finer and purer than the dust samples taken from the mine, but there was not enough difference between this dust and that found in certain parts of the mine, to affect the results materially. For convenience, therefore, the dust used in the explosion tests in the experimental mine was ground from lump coal.

The average of the analyses and screen tests of the dust used in tests 162 to 174 are as follows:

Average results of analyses and screen tests of anthracite used in explosion tests in the experimental mine.

Proximate analysis:

Moisture.....per cent..	1.03
Volatile matter.....do....	8.47
Fixed carbon.....do....	76.97
Ash.....do....	13.52
Moisture and ash.....do....	14.55
Ratio of volatile matter to total combustible..per cent..	9.91

Ultimate analysis:

Hydrogen.....per cent..	3.25
Nitrogen.....do....	.94
Carbon.....do....	79.51
Oxygen.....do....	2.08
Sulphur.....do....	.66
Ash.....do....	13.56

Fineness:

Through 100-mesh.....per cent..	100
Through 200-mesh (screen A).....do....	90
Through 240-mesh.....do....	83

In these tests no attempt was made to reproduce the actual mine conditions, but they were made under the usual experimental conditions. The purpose was to determine the relative explosibility of the coal dust as compared to other coals, under the most favorable conditions for an explosion.

The series comprised, in all, 20 explosibility tests, in most of which the dust ground from Lykens coal was used, the others being blank tests to determine the length of flame from different ignition methods. The six tests with numbers below 140 were made before the inner end of the mine was concreted. Fourteen tests (Nos. 162 to 176) were made after the concreting was done, and the dusts therefore could not have been contaminated by dust from the coal ribs.

The tests in this series may be classified as follows:

Ignition tests:

- A. Blown-out shot ignition, no gas, pure Lykens Valley anthracite dust (tests 121, 121B, 135, 135B, 162, and 172).
- B. Blown-out shot ignition, gas in air current, no dust (test 137).
- C. Blown-out shot ignition, gas in air current, pure Lykens Valley anthracite dust (tests 136, 163, 164, 173, and 174).

Propagation tests:

- D. Blown-out shot ignition, 50-foot ignition zone of pure Lykens Valley anthracite dust, gas in air current, mixtures of Lykens Valley anthracite dust and shale (tests 168, 169, 170, and 171).
- E. Ignition of 50-foot zone of an explosive mixture of gas, no gas in ventilating current, no dust (tests 167 and 176).
- F. Ignition of 50-foot zone of an explosive mixture of gas, no gas in ventilating current, pure Lykens Valley anthracite dust (tests 165 and 166).

The results of the tests on this anthracite are tabulated in Table 38.

TABLE 38.—Results of standard tests of anthracite coal dust from Iykens Valley, Pa.

[Size of coal dust used, pulverized; size of pit-shale dust used, pulverized. Originating cause: Standard blown-out shot from cannon at station E 1300. In the ignition tests 25 pounds of coal dust was placed on the platform in front of the cannon in addition to the regular loading at the rate given in the table. The mixed-dust zones, except as otherwise noted under remarks, extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In propagation tests 168, 169, 170, and 171, the originating cause was a standard blown-out shot from cannon at station E 1300. The ignition zone (pure Lykens Valley anthracite coal dust) extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In propagation tests 167, 176, 165, and 166, the originating cause was ignition of a 50-foot zone of an explosion mixture of natural gas and air. The gas zone extended from stations E 1300 to E 1250, 50 feet. The mixed-dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet.]

IGNITION TESTS.

Test No.	Date.	Dust used in mixed-dust zones.			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.					Length of flame in mixed-dust zone.	Remarks.
		Ratio of coal dust to pit-shale dust in mixture.	Calculated concentration of dust in container.	Rate of loading.	Total loading.	Per cent.	Natural gas used.	Station 1150.	Station 950.	Fall at station 1250.	Fall at station 1150.	Fall at station 1050.	Fall at station 950.	
121	June 15, 1914	(a)	9.6	2.00	1,225	0.0	0.0	0	0	Sec. per onds.	Sec. per onds.	Sec. per onds.	Sec. per onds.	Ignition not obtained. Dust loaded to station 1050 only, in the air course.
121B	do.	(a)	9.6	(b)	1,255	0	0	0	0	Sec. per onds.	Sec. per onds.	Sec. per onds.	Sec. per onds.	Loading comprised residue of test 121, plus 30 pounds of fresh dust on platform in front of cannon. Ignition not obtained.
135	July 6, 1914	(a)	16.0	2.00	1,425	0	0	1	0	1.237				Ignition not obtained.
135B	do.	(a)	16.0	2.00	1,400	0	0	1	0	1.442	43	3.750		From E 1300 to E 1250, 100 pounds fresh dust was added; the remainder of some comprised residue of test 135. Ignition not obtained.
162	Jan. 26, 1915	(a)	12.7	2.00	1,425	0	0	0	0					Ignition not obtained.

TABLE 38.—*Results of standard tests of anthracite coal dust from Lykens Valley, Pa.—Continued.*
PROPAGATION TESTS (GAS-IGNITION ZONE).

Test No.	Date.	Dust used in mixed-dust zones.				Natural gas used.	Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.
		Ratio of coal dust to shale dust in mixture.	Calculated combustible dust content.	Rate of loading.	Total loading.			Station 1150.	Station 950.	Fall at station 1250.	Velocity.	Fall at station 1150.	Velocity.	Fall at station 1050.	Velocity.			Fall at station 950.
		Per cent.	Lbs. per ft.	Lbs.	Per cent.	Entry..... {Air course.....	Lbs. per sq. in.	Lbs. per sq. in.	Sec. onds.	Feet per sec.	Sec. onds.	Feet per sec.	Sec. onds.	Feet per sec.	Sec. onds.	Feet.	
167	Jan. 29, 1915	None.			0.0	{Entry..... {Air course.....	5 7	4	0.613	103	1.587					95 55	Test to determine the length of flame from the explosion of a 50-foot body of a mechanically mixed natural gas and air mixture containing about 10 per cent of gas.
176	Feb. 15, 1915	None.			.0	{Entry..... {Air course.....		4	.477							50 40	Do. Pure coal dust was loaded at the rate of 5 pounds per foot from E 1200 to E 1205 and at 2 pounds per foot in remainder of dust zones. Gas in 50-foot zone not mechanically mixed with air. Propagation not obtained.
165	Jan. 27, 1915	(a)	15.5	(b)	1,700	.0	{Entry..... {Air course.....	0 0	4.111							65 50	Approximately 10 per cent natural gas, in 50-foot zone, mechanically mixed with air. Propagation obtained.
166	Jan. 28, 1915	(a)	15.5	(b)	1,700	.0	{Entry..... {Air course.....	6 7	.536	110	1.463	91	2.529	65	4.530	(c)	

^a All coal.

^b See "Remarks," last column of table.

^c The propagation test was not the later standard propagation test, as the ignition zone was loaded with Lykens Valley dust and not Pittsburgh standard coal dust.

^c Flame extended through zones.

DISCUSSION OF RESULTS.

IGNITION TESTS.

In the tests of group A in which pure coal dust was used, without gas, no ignition was obtained in tests 121, 121B, 135, 135B, 162, and 172. The farthest match burned was not more than 75 feet from the cannon in tests 121, 121B, and 162.

In test 172 very fine coal dust was used, but the flame extended only 100 feet from the point of ignition. This dust was obtained from the bags of the float-dust collector in the grinding house and had the following analysis:

Results of analysis of float dust used in test 172.

Moisture.....	per cent..	1. 47
Volatile matter.....	do.....	9. 79
Fixed carbon.....	do.....	61. 27
Ash.....	do.....	27. 47
		100. 00
Moisture plus ash.....	do.....	28. 94
Ratio of volatile to total combustible.....		13. 8

The moisture and ash content of this dust was somewhat higher than that of the other coal dust used, but the ratio of volatile matter to total combustible was also higher than in the other dust, which would probably offset the effect of the increased incombustible content. As no explosion was obtained with this very fine dust, it seems probable that none could be obtained with pure coal dust without gas under the standard ignition-test conditions.

In tests 135 and 135B the flame extended 150 feet and 125 feet respectively from the cannon, but this burning was in the unlined entry and there might possibly have been some contamination from bituminous dust.

Under group B, test 137 was made to determine the result of firing a standard blown-out shot into a dustless zone with the air current containing nearly 2 per cent natural gas. No explosion was produced, the last match burned being only 50 feet from the cannon.

Under group C, five tests were made with various percentages of gas in the ventilating current ranging from 1.06 to 2.54. In tests 163 and 173, with gas percentages of 1.08 and 1.30, respectively, and with the cannon at the point E 1304, no explosions were obtained.

However, in test 174 an explosion was obtained with 1.06 per cent of gas, but with the cannon placed at the point E 1247; that is, just outby the 1250 cut-through, pointing outward. This test, together with No. 175 in the series of ignition tests with Pittsburgh coal dust (see p. 152), seemed to indicate that this point of ignition was a little more favorable for obtaining an explosion in a dust of low explosibility than was the position at the face of the entry, E 1304. The

explosion in test 174, however, was very weak, the pressures being only 1 or 2 pounds at the various stations. The length of time that the flame was at station E 1150, as photographed by the manometer, was noteworthy, beginning at 0.89 and ending at 2.14 seconds after the shot was fired, or a total duration of 1.25 seconds.

In test 136 the dust was distributed on side and cross shelves in the unconcreted zone, and there was 1.72 per cent gas in the ventilating current. Ignition was obtained with maximum pressures of about 6 pounds at the outby ends of the zones.

- In test 164 ignition was obtained through the dust zone with 2.54 per cent of gas in the air current, but with low pressures.

These tests indicated that while ignition could not be obtained through the Lykens Valley anthracite dust by using the standard blownout shot with 1.08 per cent gas in the air current, it could be obtained with 1.06 per cent gas when the shot was fired from station E 1247, or with 1.72 per cent or more gas when the shot was fired from the face of the entry.

PROPAGATION TESTS, PURE LYKENS DUST IGNITION-ZONE.

The tests in group D were made in order to determine how much shale, when mixed with the Lykens Valley anthracite dust, was necessary to prevent propagation of an explosion started in a 50-foot zone of pure Lykens dust, with various percentages of natural gas in the ventilating current.

In test 168 a mixture of 80 per cent coal dust and 20 per cent shale dust was distributed in the explosion zone outby the 50-foot ignition zone of pure Lykens dust, with an average of 2.8 per cent of gas in the ventilating current. Propagation was obtained through the mixture in the main entry, but in the air course the flame extended only to station A 1050, or 250 feet outby the end of the ignition zone.

In test 169 a mixture of 70 per cent coal dust and 30 per cent shale dust was used, with 2.24 per cent gas in the air current. Propagation was not obtained, the flame extending only 81 feet beyond the end of the ignition zone in either the entry or the air course.

In test 170 the dust mixture used was the same as in test 169, but the quantity of dust in the cut-through and throughout the zone in the main entry was doubled, being 4 pounds of coal dust per foot of entry. The gas percentage was raised to 2.74 per cent. Notwithstanding the increased loading of dust and the additional amount of gas, the flame did not extend as far in this test as it had extended in test 169.

In test 171 the same dust mixture—70 per cent coal dust and 30 per cent shale dust—was again used, but with 3.26 per cent gas in the air current. Propagation was obtained through both zones but with comparatively light pressures.

These tests indicate that the 30 per cent shale dust and 70 per cent Lykens coal dust mixture, which contains about 40 per cent incombustible, will not propagate an explosion started in a 50-foot zone of pure Lykens dust with $2\frac{1}{4}$ per cent of natural gas in the air current, but will propagate with $3\frac{1}{4}$ per cent.

PROPAGATION TESTS, GAS-IGNITION ZONE.

To parallel mine conditions encountered not infrequently, a group of tests was arranged, in which an explosive gas mixture served as a source of ignition at the head of the entry.

In test 165 an ignition zone consisting of an explosive gas-and-air mixture extending from the face to the cut-through was prepared, the gaseous mixture being held in place by a diaphragm as described on page 175. The coal-dust zone was prepared outby E 1250 in both entries, and 300 cubic feet of gas were passed through the paper diaphragm inby E 1250. The capacity of this zone was about 3,000 cubic feet. In this test the gas was not mixed with the air mechanically, and so was probably concentrated more or less near the roof. No attempt was made to take samples from this zone. Ignition was obtained by firing electric black powder igniters at two points in the zone. The flame extended to E 1185 and A 1250, or 65 and 50 feet beyond the ignition zone, in each direction from the paper diaphragm.

In tests 167 and 176, the gas introduced behind the diaphragm was mechanically mixed by a fan, as described on page 175. Tests 167 and 176 were to determine the length of flame from the body of gas, no dust being present, also to determine the resulting pressures.

In test 166 a similar volume of gas was turned into the 50-foot zone behind the paper diaphragm, but was mixed with a fan as described for tests 167 and 176. The residue of the dust used in test 165 was left in the mine and fresh dust was added in the air-course zone. Propagation was obtained throughout both zones, pressures of 6 and 7 pounds being recorded at stations E 1150 and A 1150, respectively, and 4 pounds at station A 950.

The tests in group F indicate that an explosion may be propagated with the Lykens Valley anthracite dust when started by an explosive mixture of gas and air, even when there is no gas in the ventilating current. Comparison of these tests with previous tests indicates that an explosive mixture of gas of this volume is more effective in starting an explosion than the standard blown-out shot.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE ANTHRACITE DUST.

The results of the entire series of tests on Lykens Valley anthracite dust indicate that an explosion can not be started by means equivalent to the standard blown-out shot if there is no gas present in the ventilating current.

An explosion may be originated by a blown-out shot and propagated with Lykens coal dust if there is 1 per cent or more of gas present.

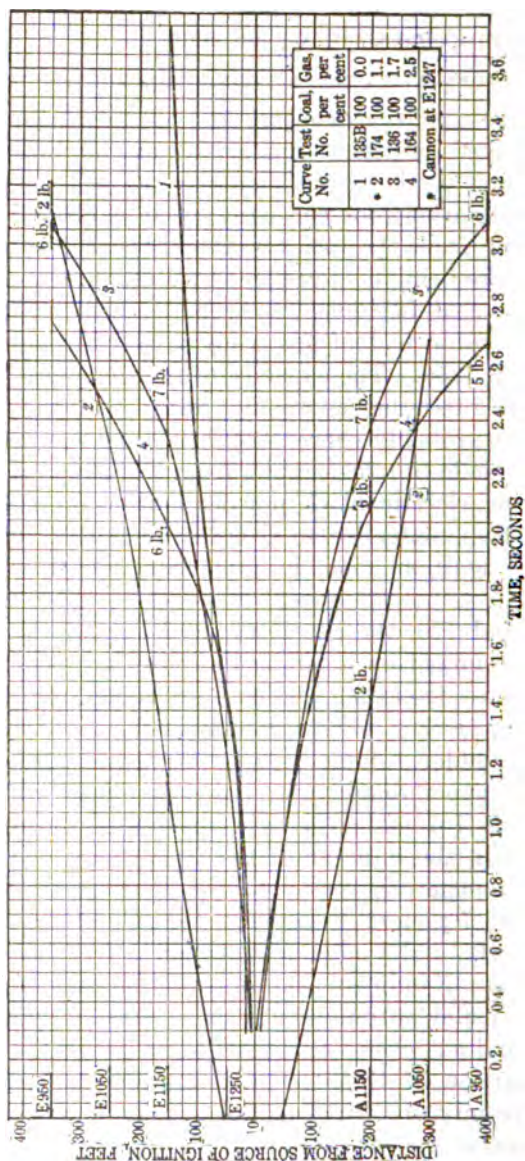


FIGURE 44.—Flame-velocity curves for ignition tests of Lykens Valley anthracite dust. Figure in *italic* denotes number of curve; figure in roman denotes pressure developed in pounds per square inch at point indicated.

The flame velocities of the ignition tests in this series are shown in figure 44 and those of the propagation tests in Plate XIII.

EXPLOSIBILITY TESTS OF ANTHRACITE COAL DUST FROM THE BERNICE FIELD, PENNSYLVANIA.

In the various coals that had been tested up to the fall of 1915 the variation in explosibility seemed to be due mainly to the percentage of volatile matter. Therefore it seemed desirable to make some explosibility tests on coals having ratios of volatile matter to total combustible similar to ratios of coals that had already been tested, and particularly to coals having very low ratios, concerning which there was some doubt as to their explosibility. For this reason a 5-ton sample of lump coal was obtained from the Bernice field, a small basin lying northwest of the principal anthracite basins. This coal had a ratio almost the same as that of the Lykens Valley anthracite. Four explosion tests were made in the experimental mine in the winter of 1916.

CONDITIONS IN MINE WHERE SAMPLE WAS OBTAINED.

In order that comparison might be made between the dusts used in the explosibility tests and the dust naturally occurring in the mine during operation, a visit was made to the mine and samples of road dust were taken. The following table gives the analysis and the screen tests of each sample:

Results of analyses and screen tests of the road dusts from an anthracite mine in the Bernice field, Pennsylvania.

Laboratory No. of sample.	Analyses as received.				Moisture plus ash.	Ratio of volatile to total combustible.	Screen test, per- centage of 20-mesh dust through—	
	Moisture.	Volatile matter.	Fixed carbon.	Ash.			100-mesh screen.	200-mesh screen.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>			
23763	2.30	11.69	48.89	37.12	39.42	19.29	31.3	16.4
23777	3.13	11.94	58.74	26.19	29.32	16.90	25.7	13.1
23791	2.12	11.02	58.65	28.21	30.33	15.82	29.8	15.1
23805	1.78	12.02	53.97	32.23	34.01	18.22	31.1	14.9
23819	3.20	10.67	63.72	22.41	25.61	14.34	27.2	15.7
23833	2.36	8.83	44.18	44.63	46.99	16.65	30.0	19.5
23847	2.47	10.57	32.51	54.45	56.92	24.54	24.5	15.1
23861	1.57	9.74	14.08	74.61	76.18	-----	17.0	8.8

The ratios of volatile to total combustible in these proximate analyses of road dust differ so widely and are so greatly in excess of the ratios for ground coal as shown below that they indicate the impurities must contain considerable volatile matter or more likely water of composition.

The percentage of incombustible of these samples varies from 25.61 to 76.18 per cent, whereas the percentage of the 20-mesh dust that will pass through 200-mesh ranges from 8.8 to 19.5 per cent.

Seven mine air samples were taken and indicated practically no methane, the highest showing only 0.02 per cent.

DETAILS OF THE EXPLOSION TESTS.

PROCEDURE AND RESULTS.

One ignition test and three propagation tests were made, results of which are shown in Table 39. The average of the analyses and screen tests of the samples of dust used in the tests were as follows:

Average analysis and screen test of the Bernice anthracite.

Analysis:

Moisture.....	per cent..	1. 16
Volatile matter.....	do....	8. 95
Fixed carbon.....	do....	78. 73
Ash.....	do....	11. 16

100. 00

Moisture and ash.....	do....	12. 32
-----------------------	--------	--------

Ratio of volatile to total combustible.....	do....	10. 20
---	--------	--------

Fineness:

Through 100-mesh.....	do....	99. 0
Through 200-mesh (screen A).....	do....	87. 2
Through 200-mesh (screen B).....	do....	67. 5

TABLE 39.—Results of standard tests of anthracite coal dust from the Bernice field, Pennsylvania.

[Originating cause: Standard blown-out shot from cannon at station E 1300. No shale dust was used in this series, only pure pulverized coal dust. In the ignition test the anthracite dust zones extended from stations E 1300 to E 950, 350 feet, and from stations E 1250 to A 950, 350 feet; total length, 700 feet. In the propagation tests the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The anthracite dust zones extended from stations E 1250 to E 950, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

IGNITION TEST.

Test No.	Date.	Anthracite dust.		Natural gas used.	Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocities between stations.						Length of flame in anthracite dust zone.	Remarks.	
		Calculated combustible content.	Rate of loading.			Total loading.	Station 1150.	Station 950.	Foil at station 1250.	Velocity.	Foil at station 1150.	Velocity.	Foil at station 1050.			Velocity.	Foil at station 950.
		Per cent.	Lbs. per ft.	Lbs.	Per cent.	Entry.....	Lbs. per sq. in.	Lbs. per sq. in.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	Ft. per sec.	Sec. onds.	} Ignition not obtained.
276	Jan. 31	13.1	2.00	1,400	2.17	(Air course.	1	1	1.396	.....	.....	.....	.....	.....	.....	

PROPAGATION TESTS.

276	Jan. 27	10.2	2.00	1,300	0.0 {Entry..... {Air course.	1	1	0.427	30	3.763	.....	.....	.....	50 75	Propagation not obtained.
279	Feb. 1	12.8	2.00	1,300	1.91 {Entry..... {Air course.	1	1	.426	218	.884	58	2.599	.....	250 275	Do.
280	Feb. 3	13.3	4.00	2,600	2.15 {Entry..... {Air course.	1	2	.419	219	.876	87	2.032	127	2.820 2.782	Propagation obtained.

^a Flame extended through zone.

DISCUSSION OF TESTS AND RESULTS OBTAINED.

IGNITION TEST.

In test 278 dust was distributed from the cannon at the rate of 2 pounds per foot of entry, and 2.17 per cent natural gas was turned into the ventilating current. Ignition was not obtained, the flame extending only 100 feet from the cannon, as indicated by the bromide recorders.

PROPAGATION TESTS.

On account of the inconvenience and danger of using the explosive gas mixture for an ignition zone as described in the tests of Lykens Valley anthracite, this method was not used for further tests. The tests had shown that the zone of the same length loaded with pulverized Pittsburgh coal dust and ignited by means of the standard blown-out shot gave practically the same pressures and length of flame into a dustless zone as the explosion of the gas zone. The Pittsburgh coal dust was therefore used in the ignition zone for propagation tests of other coals.

In test 276 propagation was not obtained with pure Bernice anthracite dust in the test zone without gas in the air current. The flame extended beyond the end of the ignition zone 50 feet and 75 feet, respectively, into the two dust zones.

Complete propagation was not obtained in test 279 with pure anthracite dust in the test zone and 1.91 per cent natural gas in the air current. The flame extended 275 feet from the ignition zone into the air course. The pressures, however, were very light, being only 1 pound per square inch at the recording stations.

In test 280 the quantity of coal dust was doubled, making 4 pounds per foot of entry, and 2.15 per cent of gas was turned into the air current. A weak explosion resulted, 2 pounds being the maximum pressure recorded.

CONCLUSIONS AS TO EXPLOSIBILITY OF THE BERNICE ANTHRACITE DUST.

As the dust used in the explosion tests, although much finer and with a much smaller content of incombustible material than the mine dust, would not propagate unless 2 or more per cent of gas was present in the air current, it seems highly improbable that an explosion could be propagated by dust from this anthracite under the conditions found in the mine at the time of the investigation.

Comparison of the tests on the Bernice anthracite with those on the Lykens Valley anthracite indicates that the former has even less explosibility with small percentages of gas in the air. As there was very little difference in the sizes of the dusts tested, it is possible that the slight difference in the results obtained is due to some extent to the character of the coal structure. The anthracite from the Bernice mine is much harder than that from Lykens Valley.

EXPLOSIBILITY TESTS OF ANTHRACITE DUST FROM THE WYOMING VALLEY, PENNSYLVANIA.

The report of the first series of the British coal-dust experiments, conducted in a steel testing gallery at Altofts, has on page 177 a report of a test of Welsh anthracite. This anthracite had the following composition:

Results of analysis of Welsh anthracite.

Moisture.....	per cent..	1. 40
Volatile matter.....	do....	7. 58
Fixed carbon.....	do....	87. 12
Ash.....	do....	3. 90
		100. 00
Moisture plus ash.....	do....	5. 30
Ratio of volatile to total combustible.....		8. 00

A screen analysis of the dust as tested was as follows:

Results of screen test of the anthracite dust.

Through 100-mesh.....	per cent..	80. 5
Through 150-mesh.....	do....	64. 5
Through 200-mesh.....	do....	57. 5
Through 240-mesh.....	do....	34. 5

Two tests were made with this dust in zones 260 feet long. In both tests an explosion was obtained, the flame extending 20 and 25 feet beyond the end of the zone. The results of these tests aroused great interest in this country. The experience of many years had led those engaged in anthracite mining to believe that the dust was not explosive under ordinary mining conditions. In view of the results of the English tests, however, it was thought desirable to determine whether Pennsylvania anthracite was explosive, and, if it was explosive, under what conditions.

A sample of Wyoming Valley anthracite was obtained through the courtesy of an operating company, and tests were made of the dust prepared from this anthracite in the Pittsburgh steel gallery, the Bruceton steel gallery, and in the experimental mine. The preliminary tests in the steel galleries were made with various originating means, such as blown-out shots of black powder from the cannon, blown-out shots of dynamite from the cannon, ignition of an explosive mixture of gas and air, and a combination of blown-out shots of black powder, and ignition of explosive mixtures of gas and air.

GALLERY TESTS.

No explosion was obtained in any of the preliminary gallery tests, but the length of flame from the blown-out shot of black powder in the steel gallery, which is 20 feet in a dustless zone, was extended by

the dust to 70 feet. After a number of tests in the gallery had given similar results it was decided to make some tests in the experimental mine, where a longer zone could be used.

EXPLOSION TESTS IN EXPERIMENTAL MINE.

PROCEDURE.

Five tests were made in the experimental mine. These tests were made before the entries had been concreted, so that there may have been some contamination by bituminous coal dust from the ribs. If such contamination did take place it probably would help to propagate an explosion rather than to hinder it. The average analysis and screen test of the dust used in these tests was as follows:

Results of average analysis and screen test of the anthracite dust.

Proximate analysis:		Ultimate analysis:	
Moisture.....per cent..	2.77	Hydrogen.....per cent..	2.47
Volatile matter.....do....	5.72	Carbon.....do....	81.79
Fixed carbon.....do....	81.55	Nitrogen.....do....	.90
Ash.....do....	9.96	Oxygen.....do....	3.17
	100.00	Sulphur.....do....	1.01
Moisture and ash.....do....	12.73	Ash.....do....	10.66
Ratio of volatile to total com- bustible.....	6.56		100.00
Fineness:			
Through 100-mesh.....		per cent..	100.0
Through 200-mesh (Screen A).....		do....	93.8
Through 240-mesh.....		do....	92.5

RESULTS OF TESTS.

The principal data on these tests (Nos. 96 to 100) are given in Table 40. At the time the tests were made the length of the flame was measured by guncotton tufts. Later when this method was compared with photographic methods it was discovered that in some tests the guncotton tufts were burned by the heated gas from the explosion 300 and 400 feet beyond the point actually reached by the flame. The flame extensions as indicated in the table are therefore probably longer than the true value.

DISCUSSION OF THE TESTS.

In test 96 pure Wyoming Valley anthracite dust was distributed at the rate of 2 pounds per foot from the face of the entry, E 1300 to E 1200, and through the 1250 cut-through. No gas was used in this test. The farthest guncotton tuft burned was 50 feet from the cannon. In test 97 the dust zone in the main entry was lengthened to 300 feet, and dust was also distributed in the 1250 cut-through. The amount of gas used in the ventilating current was 1.11 per cent. The flame, as indicated by the guncotton tufts, extended 25 feet. In test 98 the dust remaining from test 97 was used, except that a

small amount of soot near the cannon was cleaned up. Twenty-five pounds of fresh dust was placed on the platform in front of the cannon and 50 pounds on the shelves between E 1300 and E 1250. No gas was used. The length of flame was the same as in test 97; that is, 25 feet. It was suspected that the flame was due to the powder shot alone without any assistance from the dust. In test 99, therefore, a shot was fired into a dustless zone. The length of flame was the same as in the previous test, 25 feet. In test 100 a 300-foot zone of coal dust was again used in the main entry and dust was distributed in the 1250 cut-through. An attempt was made to add 2 per cent natural gas to the air current, but on account of the strong variable wind the air current could not be kept at a constant velocity, and the percentage of gas in the various samples taken varied widely. At the time of firing the shot the gas content was between $1\frac{1}{2}$ and $2\frac{1}{2}$ per cent. Guncotton tufts were burned in both entries to distances of 150 feet from the cannon.

TESTS OF WYOMING VALLEY NO. 2 COAL.

As all of the tests mentioned were made before the testing for various coals had been standardized, it was decided to run another series of tests with this coal. At this time the test zone had been concreted. The anthracite dust to be tested was loaded along both entries instead of the single entry and was placed on cross shelves near the roof and on the concrete floor, as well as on the side shelves. Bromide recorders were used to indicate the length of flame instead of the guncotton tufts. For these tests a sample of anthracite was purchased in the Pittsburgh market which had been shipped from the same district as that used in the previous series. This coal was designated as "Wyoming Valley No. 2." The results of the tests are given in Table 40 (p. 340).

In test 243, with 2.01 per cent natural gas in the air current, ignition was not obtained, the flame extending only 50 feet from the cannon.

Propagation test (No. 244).—In this test a 50-foot ignition zone of pure Pittsburgh coal dust was used, which would give an explosion roughly equivalent to that caused by the ignition of a 50-foot body of an explosive mixture of gas and air, such as was used in the Lykens Valley tests. Pure Wyoming Valley anthracite was distributed along both entries from the ignition zone at the rate of 2 pounds per foot of entry, and 1.94 per cent natural gas was turned into the air current. Propagation was not obtained, the flame extending only 50 feet beyond the end of the ignition zone in both directions. Inasmuch as this length of flame is the same as would be obtained from the ignition zone alone, it appears that the anthracite dust did not assist in extending the length of the flame.

TABLE 40.—*Results of standard tests of anthracite dust from the Wyoming valley, Pennsylvania.*

[Originating cause: Standard blown-out shot from cannon at station E 1300. In this series only pure pulverized coal dust was used, and no shale. In the propagation test (No. 24) the ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet.]

IGNITION TESTS OF WYOMING VALLEY NO. 1 SAMPLE.

Test No.	Date.	Anthracite dust.				Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.					Length of flame in anthracite-dust zone.	Remarks.						
		Calculated incombustible content.	Extent of zone.	Rate of loading.	Total loading.		Natural gas used.	Lbs. per sq. in.	Station	Foil at station	Velocity	Foil at station	Velocity			Foil at station	Velocity				
96	1914. Mar. 16..	Per cent. 12.8	(E 1300 to E 1200.. E 1250 to A 1250.. Total length, 150 feet.	Lbs. per ft. 2 2	Lbs. 200 100 300	Per cent. 0.0	Entry.....	Lbs. per sq. in.	Station 1150.	Station 950.	Foil at station 1250.	Velocity 1250.	Foil at station 1150.	Velocity 1150.	Foil at station 1050.	Velocity 1050.	Foil at station 950.	Velocity 950.	Per ft.	60	Ignition not obtained.
98 99	Mar. 20.. Mar. 23..	13.2 (b)	(a) (b)	(a) (b)	775	.0 .86	do.. do..	0 0	0 0	0 0									25 25	Do. Test to determine the length of cannon flame in a dustless zone with 1 per cent gas present.	Ignition not obtained.
97	Mar. 20..	13.6	(E 1300 to E 1000.. E 1250 to A 1250.. Total length, 350 feet.	2 2	600 100 700	1.11	do.....	0 0	0 0										25	Ignition not obtained.	
100	Mar. 24..	11.1	(E 1300 to E 1000.. E 1250 to A 1250.. Total length, 350 feet.	2 2	600 100 700	1.5- 2.8	do.....	1 0	4.538										150	Do	

IGNITION TEST OF WYOMING VALLEY NO. 2 SAMPLE.

243	1915. Nov. 12.	12.4	E 1200 to E 950.. E 1250 to A 950.. Total length, 700 feet.	2 2 1,400	2.01	{Entry..... {Air course.	0 0	0 0	1.025					50	{Ignition not obtained.
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PROPAGATION TEST OF WYOMING VALLEY NO. 2 SAMPLE.

244	1915. Nov. 13	14.1	E 1250 to E 950.. E 1250 to A 950.. Total length, 650 feet.	2 2 1,300	1.94	{Entry..... {Air course.	2	1 1	0.383					50 50	{Propagation not obtained.
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^a Residue of dust from test 97, plus 75 pounds of fresh dust, distributed from stations E 1200 to E 1250.

^b No coal dust used

CONCLUSIONS AS TO RESULTS OF TESTS.

The tests of both series indicated that under the test conditions this anthracite dust will not propagate an explosion even when started by a combination of blown-out shot and explosive mixtures of gas and air. Therefore, it does not seem likely that the propagation of an explosion would be aided by anthracite dust of this character.

The explosive limits of coal-dust mixtures determined in the experimental mine are generally higher than those determined by surface galleries. The only explanation therefore that can be given for the propagation of an explosion by Welch anthracite of similar volatile ratio (and not so finely ground) in the Altofts gallery, is either that there is some difference in the physical structure of the dust particles, or that the lesser total incombustible—5.30 per cent as compared with 12.73 per cent of the Wyoming Valley anthracite and 12.30 per cent of the Bernice anthracite—is an important factor.

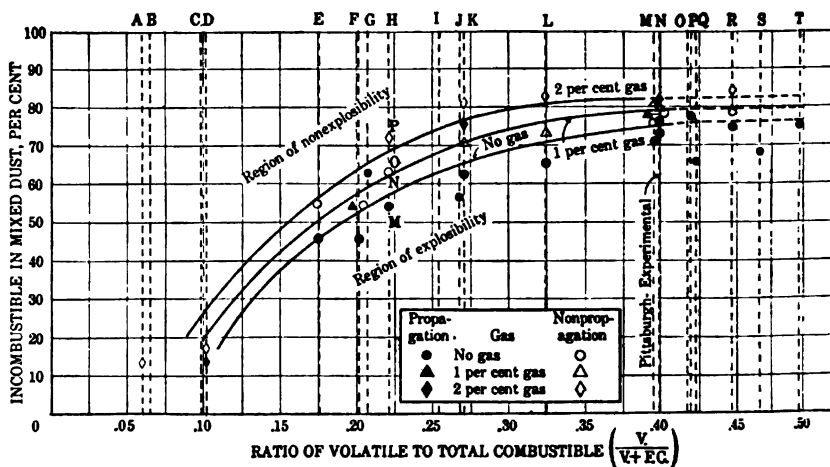


FIGURE 45.—Explosibility curves for propagation tests with pulverized dusts, showing effects of volatile matter content and of percentage of gas in air current ⁴⁴⁴.

SUMMARY OF RESULTS OF TESTS OF VARIOUS COALS.

EFFECT OF VOLATILE MATTER.

These tests on the 20 different coals show that their explosibility varies in a regular relation with the ratio of volatile matter to volatile matter plus fixed carbon or total combustible. This relation is shown in figure 45 by the lower curve, which is marked "No gas."

The different coals indicated by the letters A, B, etc., in figure 45 at the top line are shown in corresponding order in the table on page 344. The measure of explosibility is denoted by the percentage of incombustible material that must be mixed with any given coal dust to prevent propagation of an explosion by the mixture under the con-

⁴⁴⁴ As figure 45 is small, it shows only a few of the test points that control the curves.

ditions in the experimental mine. The ratios of volatile combustible to total combustible of the various coals tested are given along the bottom line. The percentages of incombustible—which includes the moisture and ash of the coal and the inert matter introduced (such as shale dust)—are given at the left of the diagram. The ratio of volatile to total combustible of each of the 20 coals tested is shown by a dotted vertical line as indicated by the letters A, B, etc. On referring to the curve it may be noted that the mixture of Beckley seam coal dust, which has a ratio of about 0.20, would not propagate an explosion if the mixture had 55 per cent incombustible material, as this point lies above the curve, and is therefore in the region of nonexplosibility with reference to this curve. On the other hand, the Pittsburgh coal dust, which has a ratio of 0.40, would require 75 per cent incombustible to prevent propagation. Likewise for any other coal dust reference to this curve will indicate the amount of incombustible necessary to prevent propagation as tested in the experimental mine.

Each of the tests represented by these curves was made with pulverized dust, all of which would pass through a 100-mesh screen and 75 to 80 per cent through a 200-mesh screen. The relation between the different coals as shown here might be somewhat different for coarser coal dusts.

EFFECT OF GAS IN THE VENTILATING CURRENT.

The effect of 1 to 2 per cent of natural gas in the ventilating current upon the explosibility of the various coal dusts when pulverized is shown by the two upper curves in figure 45. The middle curve shows the percentages of incombustible necessary to prevent propagation by mixtures of the various coal dusts when there is 1 per cent natural gas in the air current; the upper curve shows similar data for 2 per cent of gas.

Reference to the coal (Fire Creek), indicated by vertical line headed H in figure 45, for example, shows (1) that a mixture containing 55 per cent incombustible, represented by the point M, would propagate without gas present in the air; (2) that a mixture containing 60 per cent incombustible, represented by point N, would not propagate without gas but would propagate with 1 per cent; (3) that a mixture with 65 per cent incombustible, represented by point O, would not propagate with 1 per cent of gas but would with 2 per cent; and (4) that 70 per cent incombustible, represented by P, would prevent propagation with 2 per cent of gas.

In general the effect of 1 per cent of gas in the air current is roughly equivalent to the countereffect of an additional 5 or 6 per cent of incombustible material. These curves show in a striking manner the greatly increased region of explosibility when there is gas in the air current as compared to conditions where there is no gas.

EFFECT OF INCOMBUSTIBLE MATERIAL AND SIZE.

These tests have shown that it is possible to render any coal dust inexplorable by adding sufficient incombustible material along the entry where the dust may have accumulated. The following table gives the ratio of volatile to total combustible for each of the various coals tested, with the percentage of incombustible necessary to prevent propagation when there is no gas in the ventilating current:

Explosibility limits of coal dust mixed with shale dust for coals of different ratios of volatile matter to total combustible and for different sizes of coal dust.

Group 1.—Ignition, (A) pulverized dust; 95 to 99 per cent would pass through 100 mesh, 75 to 85 per cent through 200 mesh.

Group 2.—Propagation, (A) pulverized dust; 95 to 99 per cent would pass through 100 mesh, 75 to 85 per cent through 200 mesh.

Group 3.—Propagation, (B) 20-mesh dust, 40 per cent of which would pass through 200 mesh.

Group 4.—Propagation, (C) 20-mesh dust, 20 per cent of which would pass through 200 mesh.

Group 5.—Propagation, (D) 20-mesh dust, 10 per cent of which would pass through 200 mesh.

Type of coal.		Designation, source, or bed.	Ratio V V+FC	Percentage of incombustibles required to prevent—					
				Igni- tion.	Propagation.				
					1	2	3	4	5
				A	A	B	C	D	
A	Anthracite.....	Wyoming Valley No. 2, Pa.....	0.060	(b)	(c)				
B	Do.....	Wyoming Valley No. 1, Pa.....	.066	(b)	(c)				
C	Semianthracite.....	Bernice, Pa.....	.102	(b)	(c)				
D	Do.....	Lykens Valley, Pa.....	.099	(b)	.20				
E	Semibituminous...	Lower Kittanning bed, Cambria County, Pa.....	.175	.37	.48				
F	Do.....	Beckley bed, W. Va.....	.200	45	55				
G	Do.....	Upper Freeport, or E bed, Cambria County, Pa.....	.208	53	65			60	
H	Do.....	Fire Creek bed, W. Va.....	.221	52	60				
I	Do.....	Lower Kittanning, B, or Miller bed, Pa.....	.254	60	70		65	60	
J	Do.....	Coking coal bed, British Columbia....	.270	55	65	55			
K	Do.....	Sewell bed, W. Va.....	.271	61	70	70	62		
L	Bituminouscoking.	Upper Freeport, or E bed, Indiana County, Pa.....	.325	63	73				
M	Do.....	Keokee bed, eastern Kentucky.....	.396	62	76	72			
N	Do.....	Pittsburgh bed, experimental mine.....	.400	63	77	71	64	58	
O	Do.....	Trinidad coking coal, Colo.....	.418		82		64		
P	Noncoking.....	Owl Creek bed, Wyoming.....	.417	63	78	73	64		
Q	Do.....	"No. 10" bed, Illinois.....	.420		74		60		
R	Do.....	"No. 4" bed, Montana.....	.449		79		69		
S	Do.....	Vancouver Island coal.....	.468	67	78		69		
T	Do.....	"No. 5" bed, Indiana.....	.497	67	78	76			

^a Incombustible includes ash and moisture of coal, and shale or rock dust added.

^b Ignition not obtained with pure anthracite dust.

^c Propagation not obtained with pure anthracite dust.

NOTE.—3, 4, and 5 are artificially made dusts to correspond in size with samples gathered in the respective mines.

Comparison of the ignition and the propagation limits (groups 1 and 2) for the pulverized dust of any given coal shows that the percentage of incombustible necessary to prevent the propagation of an explosion already started is much higher than that required to prevent the starting of one. In other words, the dust along an entry may have enough combustible present to prevent the starting of a dust explosion at that particular point, but if the percentage is less than that given in group 2 the mixed dust might propagate an explosion started in some other part of the mine by fire damp or dust.

EFFECT OF SIZE OF COAL-DUST PARTICLES.

As shown in the previous chapter on tests of coarse Pittsburgh coal dust, the explosibility increases as the percentage of fine dust increases. The figures given in the numbered columns 1 and 2 in the preceding table apply to pulverized coal dust. The figures in columns 3, 4, and 5 apply to dusts of coarser sizes in accordance with the sizes given in the footnote of the table.

Practically, the equivalent of pulverized dust is not found segregated in mines except locally in spots, such as piles of fine machine dust or float dust on timbers. The explosibility limits obtained for this size, therefore, represent the extreme condition. However, this is as it should be, to obtain a proper margin or "factor of safety." The pulverized dust is termed "A" dust in the table. "B" dust, 20-mesh dust, of which 40 per cent passes through 200-mesh (particles coarser than 20-mesh not being rated as dust) is often found on timbers and on projections of the rib. Usually this size represents the finest and hence the most dangerous dust found in quantity in the mine. It will be observed that the propagation limits are only slightly below those for the pulverized dust, and are, in fact, higher than the ignition limits for the pulverized size of the same kind of coal.

"C" dust, 20-mesh dust, of which 20 per cent passes through 200-mesh, represents perhaps the finest limit of ordinary road dust. The propagation limits of this size are considerably lower than those of pulverized dust of the respective kind of coal and are very close to the percentages for ignition. It is interesting to note that with "C" dust there is very little difference in limits for the different kinds of coal varying from semibituminous coal, with a ratio of volatile to total combustible of 0.25 to 1, up to a noncoking coal with a volatile ratio of 0.47 to 1. The propagation limits of eight dusts tested varied only from 60 up to 69 per cent.

"D" dust, 20-mesh dust of which 10 per cent passes through 200 mesh, represents the coarsest road dust found (as before stated, only road-dust particles passing through a 20-mesh sieve are rated as dust). Three tests of dust of this size show a slightly lower propagation limit than for the "C" dust of the same coal; also there appears to be very little difference in the limits as between dust from a coal with a volatile ratio of 0.21 and a volatile ratio of 0.40.

The tests indicate that the pulverizing of coal dust tends to destroy the natural structure of the coal particles, and the percentages of the explosibility limits for dusts from various kinds of coal follow closely the varying percentages of volatile matter content, as may be observed in the propagation curves (fig. 45). The natural structure of the coal particles is evidently of great importance as regards the danger of dust explosions in mines, because the splint-coal mines of West

Virginia and the subbituminous coal mines of the Rocky Mountain region have been free from dust explosions, whereas the artificially made dusts from the subbituminous coals have indicated a high degree of explosibility. The splint-coal dusts have not yet been tested.

EFFECT OF WATER ON COAL-DUST MIXTURES.

The limits of explosibility given in the table would also be affected by the amount of moisture present, the figures given being for practically dry dust. As the principal factor in stopping an explosion is the absorption of heat and consequent lowering of temperatures it is to be expected that water mixed with the coal dust would be much more effective than dry rock dust in a mixture, because the amount of heat required to change a given weight of water to steam is many times greater than that which would be absorbed by the same weight of rock dust. A group of tests has shown that small percentages of free moisture have about twice the effect of the same percentage of dry dust in reducing the explosibility (see p. 394). Of course, where there is enough moisture present to render the dust pasty, so that it can not be raised into a cloud, the resulting mixture would not be explosive, regardless of the percentage of incombustible present.

The disadvantage of the watering method is the necessity of constant use; omission of watering for a single day may lead to a disastrous explosion. Furthermore, in many mines efficient watering of the ribs and roof causes disintegration and falls.

IRREGULARITY IN THE RELATION OF EXPLOSIBILITY TO VOLATILE-MATTER CONTENT.

While the explosibility limits of the various coals follow the curves with remarkable consistency throughout the middle range of these tests, there appear to be some slight differences at both the lower and upper ranges of percentages of volatile matter. This is particularly true with reference to the limits of Lykens Valley anthracite and Bernice anthracite, the latter being slightly less explosive in air containing some methane.

In the upper range the Wyoming subbituminous coal and the Indiana No. 5 coal appear to be slightly less explosive than had been anticipated, except when the dust is thoroughly dried out. This is probably due to the high percentage of moisture contained by both of these coals in their natural state.

DESIRABILITY OF FURTHER TESTING.

Further testing with various other coals is desirable in order to check the results so far obtained. This is particularly necessary with regard to coals having the same explosive ratio as some of those which have already been tested in order to give better opportunity to study the effect of the physical structure of the coal.

CHAPTER VII.—TESTS WITH ORIGIN AT POINTS OTHER THAN FACE OF MAIN ENTRY.

TESTS WITH ORIGIN NEAR MOUTH OF ENTRY.

In connection with the studies of the effect of mine openings extending to the surface and of branching passages, room openings, and enlargements in the passages traversed, upon the ease of starting and propagating coal-dust explosions, a series of explosion tests was made in the main entry of the experimental mine near the drift mouth.

The objects of the series were (1) to determine how near the mouth of the entry it would be possible to start an explosion of coal dust under test conditions, (2) to determine the minimum charge of powder in the cannon which would start a dust explosion near the mouth, and (3) to determine the effect of pointing the cannon inby or outby.

Previous to this series and during the International Conference of Mine Experiment Stations two explosion tests of the same character as those described in the following series had been undertaken, at the request of the foreign representatives at the conference, by starting explosions in the main entry 500 and 550 feet, respectively, from the mouth of the mine. These tests (Nos. 16 and 17) are described elsewhere.⁴⁵

In test 16 the cannon was 500 feet from the mouth of the mine and pointed outby, and coal dust was distributed from the cannon to the mouth of the mine. The flame of the explosion resulting from the blown-out shot extended 175 feet into the open air. It also extended 50 feet inby the cannon in a zone where there was no coal dust loading.

In test 17 the cannon was placed 550 feet from the mouth of the mine and pointed outward, the coal-dust loading extending from the cannon to the mouth of the mine and also 100 feet inby. An explosion did not result, only an inflammation extending 100 feet outby from the cannon and 50 feet inby. It had rained that morning, the weather was warm, the mine surfaces were much damper than in the previous tests, and water was standing in the ditches. The coal dust had been placed two hours before the test and it is possible that this moist condition prevented explosive ignition of the dust.

⁴⁵ Rice, G. S., International Conference of Mine Experiment Stations, Pittsburgh, Pa., September 14-21, 1912: Bull. 82, Bureau of Mines, 1914, pp. 43-45.

TABLE 41.—Results of tests to determine how near the pit mouth an explosion can be initiated.

[These tests were made in order to determine effect of direction of igniting shot and to determine the minimum initiating charge. The pit mouth is at E 12. Pure coal dust was used in all tests. The heavy triple line (III) in the instrument-record columns indicates that the point of ignition lies between the two adjacent records, and that the records should be read to the right and to the left from this point.]

PULVERIZED DUST.

Test No.	Date.	Coal-dust zone.	Loading.		Cannon.		Pressure developed (pounds per square inch).				
			Per foot.	Total.	Locality.	Direction pointed.	Charge of powder.	Station E 150.	Station E 350.	Station E 550.	Station E 750.
			Pounds.	Pounds.			Pounds.				
378	1917.	E 355 to E 680.	2	650	E 390.	Inby.	4	10	14	20	66
416	Feb. 1	do.	2	650	do.	Outby.	4	19	31	63	66
417 ^a	Apr. 18	E 180 to E 580.	2	800	do.	do.	4	9	30	81	51
418 ^a	Apr. 20	E 80 to E 480.	2	800	do.	do.	4	3	4	9	8
420	Apr. 23	E 12 to E 262.	2	500	E 112.	Inby.	4	III	III	1	3
421	Apr. 26	do.	2	500	do.	do.	4	III	III	1	3
421	Apr. 27	do.	2	500	do.	do.	4	III	III	1	3
419	Apr. 25	E 12 to E 512.	2	1,000	do.	Outby.	4	3	1	1	3
422	Apr. 30	E 80 to E 480.	2	800	do.	do.	2	3	4	3	3
424	May 3	E 80 to E 300.	2	440	do.	Inby.	1	4	4	3	1
423	May 2	E 80 to E 480.	2	800	do.	Outby.	1	2	2	2	1

20-MESH DUST, 10 PER CENT 20-MESH.

377	1917.	E 355 to E 680.	2	650	E 390.	Inby.	4	1	1	1	1
379	Feb. 7	E 280 to E 680.	2	800	do.	do.	4	1	1	1	1

PULVERIZED DUST.

Test No.	Date.	Time of tin-foil rupture at stations and flame velocity between stations.												Length of flame in coal-dust zone.	Remarks.	
		Station E 150.	Ve-locity.	Station E 250.	Ve-locity.	Station E 350.	Ve-locity.	Station E 450.	Ve-locity.	Station E 550.	Ve-locity.	Station E 650.	Ve-locity.			
378	1917. Feb. 1	Seconds. 1.334	Feet per second. 403	Seconds. 1.066	Feet per second. 168	Seconds. 0.490	Feet per second. 111	Seconds. 0.832	Feet per second. 336	Seconds. 1.130	Feet per second. 847	Seconds. 1.248	Feet per second. 3,333	Seconds. 1.278	Through zone.	Violent ignition obtained.
416	Apr. 18	1.140	441	.913	260	.528	111	.780	654	.933	2,326	.976	4,348	.999	do.	Do.
417	Apr. 20	.803	690	.658	111	.779	1,538	.844	2,857	.879	2,778	.915	960	1.016	do.	Do.
418	Apr. 23	.027	111	1.054	36	3.880	283	4.181	383	4.42					do.	Ignition obtained.
420	Apr. 26	.561													63 feet inby, 40 feet outby.	Ignition not obtained.
421	Apr. 27	1.702													87 feet inby, 150 feet outby.	Do.
419	Apr. 25														28 feet inby, 130 feet outby.	Do.
422	Apr. 30	.784	111	2.360	25	6.358	37	9.041	31	12.280					Through zone.	Weak ignition obtained.
424	May 3	.923	111	1.267	36	4.072	36	6.846	113	7.732					do.	Do.
423	May 2	.990		6.613											70 feet inby, 190 feet outby.	Ignition not obtained.

20-MESH DUST, 10 PER CENT 200-MESH.

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^a Flame velocity and pressure curves of tests 417 and 418 are shown in figures 74 and 75.

DUST CONDITIONS IN LATER SERIES.

In the later series of explosions initiated near the mouth of the mine, the starting arrangements used were the same as described on page 67; that is, the cannon rested on the roadway midway between the ribs, and a platform 16 feet long was placed on the floor in front of the cannon. In some of the tests the cannon and platform pointed inby and in others they pointed outby. In a few of the later tests of this series the powder charge in the cannon was reduced.

These tests were all made with pure Pittsburgh coal dust, all but two being with 100-mesh dust, which had an average sizing test as follows: Through 100-mesh, 99.3 per cent; through 200-mesh, 82.2 per cent.

For the first 50 feet in front of the cannon the coal dust was distributed upon the platform, upon the standard side shelves, and upon the floor and roadway. This part of the mine was not cement lined, so it was impossible to clean the mine surfaces between tests as thoroughly as could be done in the cement-lined zone. Inby the first 50-foot zone from the cannon most of the dust loading was placed on cross shelves near the roof, with small amounts thrown on the ribs and on the floor. The cross shelves consisted of 1-inch by 10-inch boards sprung between the ribs. The coal dust was distributed at the rate of 2 pounds per linear foot of entry in all of the tests. The main data on the results of these tests are shown in Table 41.

In the system of designation used for points in the entry, the zero point is taken at the end of the pit-mouth wall, which places the actual opening at E 12. Consequently point E 380 is 380 - 12 or 368 feet from the pit mouth. In test 378 (see Table 41), a violent ignition was obtained with the cannon at E 380. The cannon pointed inby and the dust was loaded 25 feet outby and 300 feet inby. The flame traveled both ways far beyond the dust loading. Pressures as high as 66 pounds per square inch were recorded.

In test 416 the arrangements were the same as in test 378, except that the cannon pointed outby; a more violent explosion was obtained than in the earlier test.

In test 417 the cannon was moved 100 feet nearer the mouth, and pointed outby. The dust loading extended for 100 feet outby the cannon in addition to the 300-foot zone inby. A violent explosion resulted, the flame extending a distance of 50 feet out into the open air as well as traveling inby 200 feet beyond the dust zone.

The cannon was then moved outward another 100 feet, the point of ignition being 168 feet from the pit mouth with cannon pointing outby. A fairly strong explosion was obtained with this arrangement in test 418. The flame traveled 145 feet beyond the test zone inby, and extended 150 feet into the open air.

The cannon was then moved to a point 100 feet from the pit mouth and tests 419, 420, and 421 were made, two with the cannon pointing inby and one with it pointing outby. In all of these tests the flame came out the drift mouth, but did not travel inby more than 90 feet from the point of ignition.

The cannon was then moved to the point 168 feet from the pit mouth where ignition had been obtained in test 418, and the charge of powder was reduced in order to determine the minimum amount that would initiate an explosion.

In test 424 a weak ignition was obtained with a 1-pound charge of powder when the cannon was pointing inby, but in test 423 ignition was not obtained with the cannon pointing outby, the same amount of powder being used. In this latter test flame came out the mouth of the entry, but did not travel to the inby end of the dust zone. By referring to Table 41, however, the reader will note that the pressures in these two tests were almost the same, showing that there is not much difference in effect between the two positions of the cannon.

Two tests were made with a much coarser size of coal dust which would practically all pass through 20-mesh and of which 10 per cent would pass through 200-mesh. In both test 377 and test 379, the cannon was 368 feet from the pit mouth, pointing inby, and was charged with 4 pounds of powder, the standard amount. In one of these tests the flame traveled only 20 feet inby and in the other 70 feet. In both tests the flame traveled toward the entry mouth beyond the prepared coal dust zone.

SUMMARY OF PIT-MOUTH SERIES OF EXPLOSION TESTS.

1. An explosion propagating inby was easily obtained with the cannon 168 feet from the mouth of the entry, but explosion was not obtained with the cannon 100 feet from the mouth, regardless of the direction that the cannon was pointing.

2. An explosion was obtained with 1 pound of powder when the cannon was 168 feet from the mouth and pointing inby.

3. A slightly stronger starting effect was obtained with the cannon pointing inby as compared with the opposite direction. When the cannon was placed 168 feet from the mine mouth, a 1-pound charge fired toward the face started a very weak explosion, whereas the same charge fired toward the mine mouth failed to start the explosion.

4. A very light starting effect is necessary to cause the flame to travel toward the opening; but it is necessary to develop some pressure before the explosion will overcome the resistance of a long air column and propagate throughout the mine.

5. An explosion could not be started under the test conditions with the cannon 368 feet from the pit mouth, using 20-mesh coal dust, of which 10 per cent would pass through 200-mesh.

In conclusion, the series demonstrated that a coal-dust explosion may be started comparatively near the mine opening or the surface, provided the dust is of sufficient purity and the source of ignition is able to raise the dust mechanically into a dense cloud. Therefore it is surmised that an explosion probably would be started with a relatively less violent source of ignition than a blown-out shot if there was a premade dust cloud of sufficient density, such as might be caused by the wrecking of a trip of cars loaded with dry coal. This conclusion has an important bearing on the origin of two disastrous mine explosions investigated by bureau engineers.

TESTS TO DETERMINE THE POSSIBILITY OF ORIGINATING AN EXPLOSION IN A WORKING ROOM, AND THE EFFECTIVENESS OF ROCK-DUST ZONES.

After testing in the main entries had advanced to the point where the more important information had been obtained the problem of the initiation of explosions in working rooms was taken up. The first tests were made to determine the possibility of obtaining an explosion in an ordinary mine room with the usual arrangement of props and to obtain the characteristics of an explosion under such conditions. Later, tests were made to determine the effect of varying the quantity and size of dust present upon the characteristics. The results of these tests leave much to be determined in the future in room testing.

DESCRIPTION OF ARRANGEMENTS FOR TESTS.

Number 3 room off No. 1 butt was selected as the place in which the tests were to be made. The gob was removed and the room cleaned as thoroughly as could be done by sweeping and blowing with a jet of compressed air. All loose dust was carefully brushed from the posts and ribs. The shale floor, after exposure, becomes soft and tends to break up; therefore loose floor material was generally present to some extent in all explosions and being of an inert character had a tendency to lessen the sensitiveness of the coal-dust reactions. For this reason all the loose material was as carefully cleaned up as was possible before a test, but walking on the floor during the distribution of the dust was sufficient to loosen additional particles of shale, most of which, however, was in pieces of considerable size. It is probable that the quantity of 200-mesh material in this loose shale on the floor was less than 5 per cent. It is appreciated that the room as prepared was not similar to a working room in a mine; there the gob is usually piled full of waste rock and impure coal and contains much coal dust and incombustible dust. In preliminary tests, however, for the determination of the factors

affecting explosibility all possible variables must be eliminated or controlled. After the conditions have been learned it is possible to advance the testing to a stage where conditions represent more closely actual mine conditions.

No. 3 room at the time of making these tests was 160 feet long, measured from the center of No. 1 butt. The room neck was 26 feet long, measured from the side of No. 1 butt, and about 7 feet wide. Cut-throughs to No. 2 and No. 4 rooms were driven just inside the room neck. The widening of the room and the cut-throughs to the adjacent room were driven along the faces of the coal and conse-

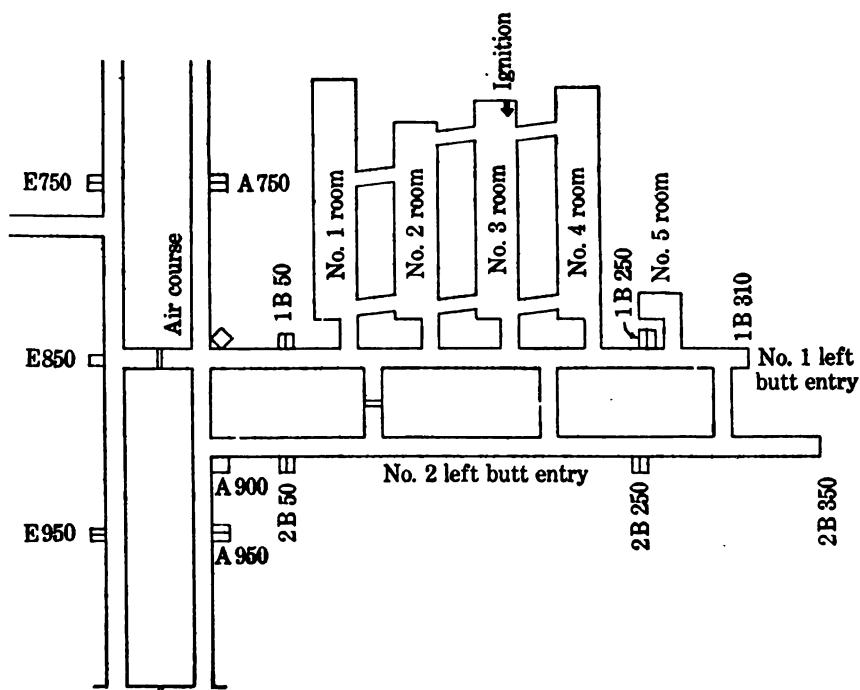


FIGURE 46.—Diagram showing conditions as arranged for tests in No. 3 room.

quently not quite at right angles to the center line of the room. At the time of running the first tests, cut-throughs to No. 2 and No. 4 rooms were being driven at a distance of 135 feet from the center of No. 1 butt. The cut-through to No. 2 room was being driven from the No. 2 room side. One cut remained to be taken out of it. This had been undercut and a hole 8 inches by 10 inches had broken through to No. 3 room. The cut-through from No. 4 room was being driven from No. 3 room and was about 20 feet deep. After a few tests had been made with the room in this condition the cut-throughs were finished and tests run to determine the effect of these new openings (see fig. 46).

GENERAL CHARACTER OF TESTS AND RESULTS.

1. Five tests (Nos. 309, 327, 330, 481, and 482) were made with pure Pittsburgh pulverized coal dust in order to determine:

(a) The possibility of obtaining ignition in one or more rooms.

(b) The effect of opening the cut-throughs near the face on the start of an explosion.

(c) The conditions under which an explosion could be originated from a blown-out shot in the coal instead of from a cannon.

2. Five tests (Nos. 310, 311, 312, 313, and 480) were made with pure 20-mesh (20 per cent 200-mesh) Pittsburgh coal dust to determine:

(a) The possibility of obtaining an explosion therewith.

(b) The effect on the explosion of opening cut-throughs near the face.

3. Five tests (Nos. 475, 476, 477, 478, and 479) were made with 20-mesh (10 per cent 200-mesh) Pittsburgh coal dust and pulverized Pittsburgh coal dust to determine the effect of quantity of loading on the explosion. Rock-dust zones were used in a number of these tests to try out their effectiveness in preventing the spread of the explosion through the butt entries and the air course.

All of the above tests not originated by a blown-out shot in the coal were started by the standard blown-out shot from the cannon. The cannon was placed at the face of the room in the center line of the track, about 3 feet from the east rib, and was pointed straight out along the track. A bench of 2-inch boards was placed in front of the cannon in a manner similar to that used at the face of the main entry. Twenty-five pounds of the dust to be tested was placed on this bench. The results of the tests are given in Table 42.

TABLE 42.—Results of tests with pure Pittsburgh coal dust to determine the possibility of obtaining an explosion in a working room and the effectiveness of rock dusting.

TESTS WITH PULVERIZED COAL DUST.

[Point of origin: At face of No. 3 room.]

Test No.	Date.	Igniting means.	Coal-dust zone.			Rock-dust zone, extent and rate of loading.	Pressure (pounds per square inch).		Time of tin-foil rupture (seconds).		Length of flame beyond coal-dust zone (feet).	Remarks.
			Description.	Rate of loading.	Amount (pounds).		1B 250	1B 50	1B 250	1B 50		
309	Apr. 11, 1916	Standard blow-out shot.	No. 3 room, 160 feet long, 20 feet wide; cut-through to No. 2 and No. 4 rooms, 130 feet from face.	2 pounds per foot on track side. 2 pounds per foot on gob side. Unfinished cut-through to No. 4 room at 3R 135.	310 260 25 595	None.....	10	9	1.171	1.044	To A 700, 330 feet; to 1B 250, 70 feet; to 2B 25, 245 feet.	Strong explosion. Cut-through from No. 2 room 25 feet from face had been undercut and a hole 8 inches by 10 inches broken through into No. 3 room. Flame passed through this hole and ignited dust on opposite side. Ignition obtained.
327	May 22, 1916	do.....	No. 3 room 160 feet long, 20 feet wide; cut-through to No. 2 and No. 4 rooms, 25 feet from face.	2 pounds per foot on track side. 2 pounds per foot on gob side. Last cut-through to No. 2 and No. 4 room	310 260 100 670	A 950 to 1B 300 and 200 cut-through to No. 2 butt, 6 pounds per foot.	6	6	.....	1.976	To 1B 75, 105 feet; to 1B 225, 45 feet. No flame in No. 2 butt.	Flame did not reach the end of the rock-dust zone; penetrated 105 feet into zone in maximum extension. Ignition obtained.
330a	May 29, 1916	do.....	Nos. 1, 2, 3, and 4 rooms, all connecting. No. 1 and No. 2 were 170 feet long, No. 3 and No. 4 were 160 feet long.	No. 1 room..... No. 2 room..... No. 3 room..... No. 4 room.....	630 630 570 590 2,720	Both butt entries and A 700 to A 950, 6 pounds per foot.	22	21	1.511	1.253	To A 375, 655 feet; to 1B 275, 95 feet; to A 950, via No. 2 butt, 320 feet.	Flame traversed the rock dust zone and extended beyond. The surfaces of the air course and both butts were wet, and the rock dust was not blown into the air. Ignition obtained.

a Flame velocity and pressure curves of test 330 are shown in figure 78.

TABLE 42.—Results of tests with pure Pittsburgh coal dust to determine the possibility of obtaining an explosion in a working room and the effectiveness of rock dusting—Continued.

TESTS WITH PULVERIZED COAL DUST—Continued.

Test No.	Date.	Igniting means.	Coal-dust zone.			Rock-dust zone, extent and rate of loading.		Pressure (pounds per square inch.		Time of tin-foil rupture (seconds).		Length of flame beyond coal-dust zone (feet).	Remarks.
			Description.	Rate of loading.	Amount (pounds).			1B 250	1B 50	1B 250	1B 50		
481	Apr. 24, 1918	Blown-out shot from 14-inch pipe embedded in coal; 4 pounds powder, 1 pound clay. See "Remarks."	No. 3 room, 160 feet long, 20 feet wide; cut-throughs to No. 2 and No. 4 rooms, 25 feet and 130 feet from face.	3,000 square feet, 0.2 pound per square foot. 4 cut-throughs to No. 2 and No. 4 rooms.	600 200 800	None.....	2	2	2	.....	.....	To 1B 150, 30 feet..	Hole for shot drilled horizontally, started 3 feet from east rib. Center line of hole intersects east rib 44 feet from face. Powder occupied 3 feet 5 inches of pipe, tamping occupied 6 inches of pipe. Ignition obtained.
482	Apr. 26, 1918	do.....	do.....	do.....	800	None.....	2	2	2	.....	.....	.....do.....	Hole for shot drilled horizontally in center of face 1 foot from floor, pointing at right angles to face. Ignition obtained.

TESTS WITH 20-MESH DUST, 20 PER CENT 20-MESH.

[Point of origin: At face of No. 3 room, except in test 480.]

310	Apr. 14, 1916	Standard blown-out shot.	No. 3 room, 160 feet long, 20 feet wide; cut-throughs to No. 2 and No. 4 rooms, 130 feet from face.	2 pounds per foot on track side. 2 pounds per foot on gob side. Unfinished cut-through to No. 4 room at 2R 136.	310 200 25 595	None.....	5	4	1.969	1.964	To A 640, 390 feet; to B 250, 70 feet; to 2B 126, 145 feet.	Flame did not pass through small hole described under remarks for test 309. Ignition obtained.
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311	Apr. 18, 1916	Blown-out shot from 14-inch pipe embedded in face; 4 pounds powder, 3 pounds clay.	do.....	do.....	595	No. 1 butt and 200 cut-through to No. 2 butt rock dusted, 5 pounds per foot.	0	0	Flame extended not over 35 feet from face.	Shot did not blow out. Pipe was broken and part of it thrown to outer end of room. Hole torn in face. Amount of coal displaced therefrom, 4 to 5 cubic feet.
312	do.....	Standard blown-out shot.	do.....	do.....	595	do.....	3	2 803 2 194	To 1B 50, 130 feet; to 1B 260, 70 feet; to 2B 175, 95 feet.	Rock-dust zone extinguished the flame. Extension much shorter than in test 310; conditions identical with those for test 310, except for rock dusting. Ignition obtained.
313	Apr. 21, 1916	do.....	No. 3 room, 180 feet long, 20 feet wide; cut-throughs to No. 2 and No. 4 rooms, 25 feet and 130 feet from face.	2 pounds per foot on track side. 2 pounds per foot on gob side. 24 cut-throughs to No. 2 and No. 4 rooms.	310 240 100 670	34 pounds per foot over cutting remaining from test 312.	2	2	Flame traveled 110 feet from face in room; did not reach No. 1 butt.	Opening the last cut-throughs relieved the pressure and prevented complete ignition. Compare with test 312.
430	Apr. 23, 1918	Standard blown-out shot at face of No. 4 room, 4R 203 track.	No. 4 room, 206 feet long, 20 feet wide; cut-throughs to No. 3 and No. 5 rooms, 75 feet and 175 feet from face.	3,900 square feet at 0.2 pound per square foot. Cut-throughs to No. 3 and No. 5 rooms.	780 200 980	None.....	1	1	do.....	Additional 55 feet of loading inside of last cut-through not sufficient to cause complete ignition. Compare with test 313.

TABLE 42.—Results of tests with pure Pittsburgh coal dust to determine the possibility of obtaining an explosion in a working room and the effectiveness of rock dusting—Continued.

TESTS TO DETERMINE EFFECT OF QUANTITY OF COAL DUST.

[Point of origin: 3R 100 track. Igniting means: Standard blowout shot from cannon. Tests in No. 3 room, 100 feet long, 30 feet wide.]

Test No.	Date.	Coal-dust zone.						Pressure (pounds per square inch).	Time of inflammation (seconds).	Length of flame (feet from cannon).	Remarks.
		First zone.			Second zone.						
		Extent.	Size of dust.	Amount.	Extent.	Size of dust.	Amount.				
475	Apr. 9, 1918	3R 160 to 3R 110. Cut-through at 135 to Nos. 2 and 4 rooms.	20-mesh, 10 per cent 20-mesh do.	Pounds. 0.1 pound per square foot. 100 100 200	3R 110 to 3R 0. Cut-through at 30 to Nos. 2 and 4 rooms.	20-mesh, 10 per cent 20-mesh do.	Pounds. 0.2 pound per square foot. 440 100 540	1B 250 1B 50 3R 927 3R 107	1	60	Propagation through the entire room was not obtained.
475	Apr. 11, 1918	3R 160 to 3R 110. Cut-through at 135 to Nos. 2 and 4 rooms.	do.	0.2 pound per square foot. 200 100 300	3R 110 to 3R 0. Cut-through at 30 to Nos. 2 and 4 rooms.	do.	0.2 pound per square foot. 440 100 540	1	1	60	Do.
477	Apr. 12, 1918	3R 160 to 3R 110. Cut-through at 135 to Nos. 2 and 4 rooms.	do.	0.2 pound per square foot. 200 100 300	3R 110 to 3R 0. Cut-through at 30 to Nos. 2 and 4 rooms.	Pulverized do.	0.2 pound per square foot. 440 100 540	2	2	4.983 (b)	Propagation obtained.
479	.....	3R 160 to 3R 110. Cut-through at 135 to Nos. 2 and 4 rooms.	do.	0.1 pound per square foot. 100 100 200	3R 110 to 3R 0. Cut-through at 30 to Nos. 2 and 4 rooms.	do.	0.2 pound per square foot. 440 100 540	2	1	1.756	Flame did not reach all points in No. 3 room.

478	Apr. 15, 1918	3R 160 to 3R 110. Cut-throughs at 135 to Nos. 2 and 4 rooms.	do.....	0.05 pound per square foot. 50	3R 110 to 3R 0. Cut-throughs at 30 to Nos. 2 and 4 rooms.	do.....	0.2 pound per square foot. 440	1	1	1.852	.....	110	Propagation through the entrance room was not obtained.
			do.....	100		do.....	100						
				150			540						

^b Flame extended 30 feet beyond leading.

DETAILS OF THE TESTS.

GROUP 1—TESTS WITH PULVERIZED PITTSBURGH COAL DUST.

In test 309 No. 3 room was loaded with pure coal dust at the rate of 2 pounds per foot on the track and 2 pounds per foot on the remainder of the room. The last cut-throughs had not been opened except for the small hole (8 inches by 10 inches) leading to No. 2 room. The break-through on the No. 2 room side was cleaned and pulverized Pittsburgh coal dust placed therein to determine whether or not the flame would pass through this small hole.

The dust was ignited by a blown-out shot from the cannon. The resulting explosion was quite strong. Pressures of about 10 pounds were registered in No. 1 butt; the flame traveled out No. 1 butt and turned outby in the air course to A 700, a distance of 330 feet beyond the coal-dust zone. The flame also passed through the small hole, ignited the dust on the other side, and spread through No. 2 room. No rock-dust zones were used in this test.

Before the next test with pulverized coal (No. 327) the last cut-throughs to No. 2 and No. 4 rooms had been opened. In this test the loading was similar to that used in test 309. No. 1 butt and the 200 cut-through to No. 2 butt were rock-dusted at the rate of 6 pounds per foot. The explosion reached all points in No. 3 room, came out on the No. 1 butt, and extended to within 75 feet of the air course. The pressure in No. 1 butt was about 6 pounds. The reduction in pressure from that of test 309 was probably due largely to the opening of the last cut-throughs. The rock dust in No. 1 butt extinguished the flame and prevented it reaching the air course.

In test 330 four rooms were loaded with pulverized Pittsburgh coal dust. These four rooms were all that were driven at that time. Both butt entries and the air course from the 700 to the 950 foot points were rock-dusted at the rate of 6 pounds per foot. A very strong and prolonged explosion resulted. Pressures of over 20 pounds were registered in No. 1 butt. The flame traveled out this butt and outby in the air course, guncotton tufts and matches being burned as far as A 375. The bromide recorders did not show any flame beyond A 800. It is possible that guncotton tufts and matches on the outer end of the zone may have been burned by the continued outward rush of hot gases after the flame was extinguished. However, such a blast of hot gas would have killed men in its path. The instrument records showed a very long sustained pressure in the rooms and a continual flow of gas therefrom out the air course. The surfaces of the butts and of the air course were wet, owing to the weather, when the rock dust was applied before this test. As a result the rock dust became wet and stuck to the ribs instead of being thrown into the air, as it should have been. The effectiveness of the rock-dust application in this case is uncertain. The bromide record indicated that the flame was

extinguished before it reached the end of the rock-dust zone, but the matches and the guncotton tufts indicated that it extended a considerable distance beyond. The tests showed, however, that when several rooms became the zone of an explosion additional difficulties would be placed in the way of successful operation of rock-dust zones and barriers and that further tests would be necessary before any definite conclusions could be reached.

In tests 481 and 482 pulverized coal dust was loaded in No. 3 room at the rate of 0.2 pound per square foot, or a total of 600 pounds for the room. Fifty pounds was also placed in each cut-through to No. 2 and No. 4 room, a total of 200 pounds additional. The source of ignition was a blown-out shot from a hole in the face. In order to make sure that the shot would blow out the 4 pounds of black blasting powder was loaded into a piece of 1½-inch pipe, which was closed on the inner end with a cap. The powder occupied about 3 feet 5 inches of the pipe. Five inches of stemming, weighing about ½ pound, was used. In test 481 the hole was drilled horizontally 1 foot from the floor, starting 3 feet from the east rib and bearing toward the center of the room, so that the center line of the hole intersected the east rib 4½ feet from the face.

In test 482 the hole was drilled horizontally 1 foot from the floor in the center of the room, pointing directly out along the center line of the room. Both shots blew out, as was intended, and the flame spread throughout the coal dust in the room and out into No. 1 butt.

Tests 481 and 482 were the first of a series (not completed when this bulletin was written) to determine the effect upon the explosion of the position of the shot above the floor and the direction in which the shot is pointed. In all tests in which the cut-throughs were open the flame spread through these into the adjoining rooms and died out there from lack of combustible material.

**GROUP 2.—TESTS WITH PURE 20-MESH PITTSBURGH COAL DUST,
OF WHICH 20 PER CENT WOULD PASS 200-MESH.**

In test 310 pure 20-mesh coal dust, of which 20 per cent would pass 200-mesh, was loaded in No. 3 room at the rate of 2 pounds per foot on track and floor, the room being 20 feet wide and the track along one rib. The break-throughs, 25 feet from the face, had not been completed, but the small hole (8 by 10 inches) had been broken through from No. 2 room. This test was originated by the standard cannon shot. The flame spread out into No. 1 butt and traveled down this butt and the air course to A 640, a distance of 390 feet beyond the coal-dust zone; it did not pass through the small hole. No rock-dust zones were used in this test. In test 311 an attempt was made to start an explosion in 20-mesh (20 per cent 200-mesh) coal dust by means of a blown-out shot from the coal. This shot was too heavily tamped and did not blow out. It broke down coal about the hole and the dust was not ignited.

Test 312 was run the same day with the same loading. No. 1 butt and the 200 cut-through to No. 2 butt were rock dusted at the rate of 6 pounds per foot. The conditions of this test are therefore identical with No. 310 except that in the latter no rock dust was used. The flame spread through the room and traveled along No. 1 butt as far as the point 1B 50, 130 feet beyond the end of the coal-dust zone. It failed to reach the end of the rock-dust zone and was 250 feet shorter than in test 310, in which no rock dust was used.

Before test 313 was made the last cut-throughs to Nos. 2 and 4 rooms were opened. Otherwise the test was identical with tests 310 and 312, except that coal dust was distributed in the cut-throughs. The flame failed to travel through the entire length of the room and pass out into the No. 1 butt, as the open cut-throughs near the face relieved the pressure and prevented complete propagation.

In test 480, No. 4 room was loaded with pure 20-mesh Pittsburgh coal dust, of which 20 per cent would pass 200-mesh. This room had been driven to its full length of 206 feet, and the last cut-throughs were 70 feet from the face instead of 25, as in No. 3 room. The flame failed to reach the mouth of the room, extending beyond the source of ignition no farther than it had in No. 3 room with the cut-through close to the face. The additional 55 feet in length of room in by the last cut-throughs had no appreciable effect in extending the explosion.

GROUP 3.—TESTS TO DETERMINE THE EFFECT OF THE QUANTITY OF DUST UPON AN EXPLOSION ORIGINATED IN THE ROOM.

Five tests were made in No. 3 room to determine the minimum size and quantity of Pittsburgh coal dust that would give an explosion extending throughout the room and out into the butt entry. At the time these tests were made this room had cut-throughs opening into No. 2 and No. 4 rooms, 25 feet and 130 feet from the face. In each test the room was divided into two coal-dust loading zones. The first zone extended 50 feet from the face and included the inner cut-throughs to No. 2 and No. 4 rooms; the second zone extended from the end of the first zone to the butt entry and included the outer cut-throughs to No. 2 and No. 4 rooms. The explosion was started with a standard blown-out shot from the cannon. In test 475 pure Pittsburgh coal dust of 20-mesh size, 10 per cent of which would pass a 200-mesh screen, was used in both zones. In the first zone the rate of loading was 0.1 pound per square foot and in the second zone 0.2 pound; also, 50 pounds of coal dust was placed in each of the four cut-throughs. The flame extended only 50 feet from the cannon, complete propagation not being obtained.

In test 476 the same size of coal dust was used; the entire room was loaded at the rate of 0.2 pound per square foot, and 50 pounds of coal dust were placed in each of the four cut-throughs. The flame

extended 50 feet from the cannon, the explosion being very similar to that in test 475.

In test 477 the first zone was loaded with 20-mesh (10 per cent 200-mesh) coal dust at the rate of 0.2 pound per square foot, and 50 pounds of this size of dust was placed in each of the rear cut-throughs. The second zone was loaded with pulverized coal dust at the rate of 0.2 pound per square foot, with 50 pounds of pulverized dust in each of the first cut-throughs to No. 2 and No. 4 rooms. The resulting explosion traveled through the room and 30 feet along the butt entry, where it was extinguished by shale dust that had been thrown on the ribs and floor.

In test 479 the first zone was loaded with 20-mesh (10 per cent 200-mesh) coal dust at the rate of 0.1 pound per square foot, with 50 pounds additional in each of the rear cut-throughs. The second zone was loaded with pulverized coal dust at the rate of 0.2 pound per square foot, 50 pounds of pulverized dust also being placed in each of the outer cut-throughs to No. 2 and No. 4 rooms. The resulting explosion traveled 135 feet from the cannon. The flame did not reach all points in No. 3 room nor the butt.

In test 478 the loading in the first zone was reduced to 0.05 pound per square foot; the other conditions were the same as in test 479. The flame extended 110 feet from the cannon.

The results of these tests indicate that an explosion will not start in pure 20-mesh (10 per cent 200-mesh) Pittsburgh coal dust with sufficient pressure to propagate to the mouth of the room, at least for a rate of loading of less than 0.2 pound per square foot for this size of dust.

It seems evident that the first zone was insufficiently loaded, except in test 477, to obtain ignition. In the ignition zone of the entry tests the usual rate of loading is 2 pounds of pulverized dust per linear foot, equal to 0.17 pound per square foot. The general testing has demonstrated that the 200-mesh dust is the important factor in initiating an explosion. The loading of 0.1 pound of 20-mesh dust, 10 per cent 200-mesh dust per square foot, would give but 0.023 ounce of 200-mesh dust per cubic foot of space, or double this amount in test 476, which is less than the amount required to initiate or propagate an explosion.

EARLY TESTS WITH ORIGIN AT THE FACE OF NO. 2 BUTT.

GENERAL DESCRIPTION OF TESTS, AND RESULTS.

In the summer of 1914 the butt entries were extended to the following lengths: No. 1 butt, 300 feet; No. 2 butt, 350 feet. In the fall and early winter of that year three tests were run with the origin at the face of No. 2 butt. The results of these tests are given in Table 43.

TABLE 43.—*Results of early tests of pulverized Pittsburgh coal dust in No. 2 butt.*

[Point of ignition was at 2B 350. Originating cause was standard blown-out shot from cannon.]

Test No.	Date.	Coal-dust loading.		Records obtained at stations in—	Pressure.		Time of tin-foil rupture at stations and flame velocity between stations.				Flame extension.	Remarks.
		Zone and rate.	Total quantity.		Station 250.	Station 50.	Fol at station 250.	Ve-locity.	Fol at station 50.	Ve-locity.	Fol at station A 900.	
140	1914. Oct. 1...	2B 350 to 2B 0, 2 pounds per foot.	Pounds.	No. 2 butt.	Liba per sq. in.	Liba per sq. in.	Sec-onds.	Feet per sec.	Sec-onds.	Feet per sec.	Sec-onds.	Flame extended into the air course and traveled out the entry to station E 960. This was a trial test to obtain results. Propagation obtained, but was feeble.
		300 cut-through, 2 pounds per foot.	100	No. 1 butt.	.....	3	(a)	(a)	(a)	(a)	(a)	
		Bench.....	25									
			825									
141	Oct. 9...	2B 350 to 2B 0, 2 pounds per foot.	700	No. 2 butt.		10	(b)	(b)	(b)	(b)	(b)	Mixed dust, consisting of 80 per cent pulverized coal and 40 per cent pulverized roof shale, was distributed from stations A 875 to E 700, 3,250 pounds being used. Test was a demonstration for the American Institute of Mining Engineers. Strong propagation developed in "main" entry.
		200 and 300 cut-throughs, 2 pounds per foot.	200	No. 1 butt.	.....	.....	(b)	(b)	(b)	(b)	(b)	
		Bench.....	25									
			925									
148 ^c	Dec. 4...	2B 300 to 2B 0, 2 pounds per foot.	700	No. 2 butt.	11	13	0.576	545	0.943	108	1.342	Flame did not travel outby on air course, although there was no barrier present to stop it.
		200 and 300 cut-throughs, 2 pounds per foot.	200	No. 1 butt.	.....	7						
		Bench.....	25									
			925									

^a No record obtained.^b No record obtained. station A 750, 3 pounds.^c Flame velocity and pressure curves of test 148 are shown in figure 77.

Pressures recorded at other points were as follows: Station A 960, 9 pounds; station E 1150, 20 pounds; station E 750, 39 pounds; station E 550, 10 pounds;

DETAILS OF THE TESTS.

FIRST TEST.

The first test (No. 140), October 1, 1914, was a trial of arrangements proposed for a subsequent exhibition test before the American Institute of Mining Engineers and others, to demonstrate the ability to arrange a predetermined and indirect path of a coal-dust explosion, and to demonstrate the success of various types of rock-dust barriers. In this preliminary test a standard blown-out shot was fired at the face of No. 2 butt. The loading consisted of pure pulverized Pittsburgh coal dust loaded in No. 2 butt and the 300 cut-through to No. 1 butt. A rock-dust-protected ventilating door was installed at A 875. This had been in place since the middle of July. A rock-dust stopping was placed in the second cut-through between No. 1 and No. 2 butts and a Taffanel barrier in No. 1 butt, beginning just outby the last cut-through. There was a set of six box barriers in the air course at A700. An auxiliary zone of pure Pittsburgh coal dust was placed in No. 1 butt outby the Taffanel barrier. The explosion was weak; the flame traveled out No. 2 butt, into the air course, and along the entry to station E 950, there being no barriers in this direction to stop it. The flame penetrated a little beyond the Taffanel barrier in No. 1 butt, but was extinguished by the rock-dust stopping and the ventilating door. The pressures in this test were surprisingly low, 7 pounds being the maximum recorded. A similar single entry zone in the main entry would have given pressures of 40 pounds or more at the end of the zone. It was decided, however, that the arrangements were satisfactory for the demonstration.

SECOND TEST.

The public exhibition made on October 9, 1914, was a demonstration of the explosibility of coal dust and the efficiency of various rock-dust explosion-barrier devices. The visitors were members of the American Institute of Mining Engineers and State mine inspectors from Pennsylvania, Ohio, and West Virginia, there being from 150 to 200 visitors present. A standard blown-out cannon shot was placed at the face of No. 2 butt (see fig. 47). Pure pulverized Pittsburgh coal dust was loaded in No. 2 butt and in the 200 and 300 cut-throughs to No. 1 butt. A mixture of 60 per cent pulverized Pittsburgh coal dust and 40 per cent roof-shale dust was distributed in the air course from A 875 to A 1250, then through the 1250 cut-through and out the entry to E 700. At a number of places barriers were installed to limit the flame. A Rice concentrated barrier was placed at the end of the zone at E 700. Outby the concentrated barrier was a 200-foot auxiliary zone of pure pulverized Pittsburgh coal dust, this being terminated by a 15-shelf Taffanel

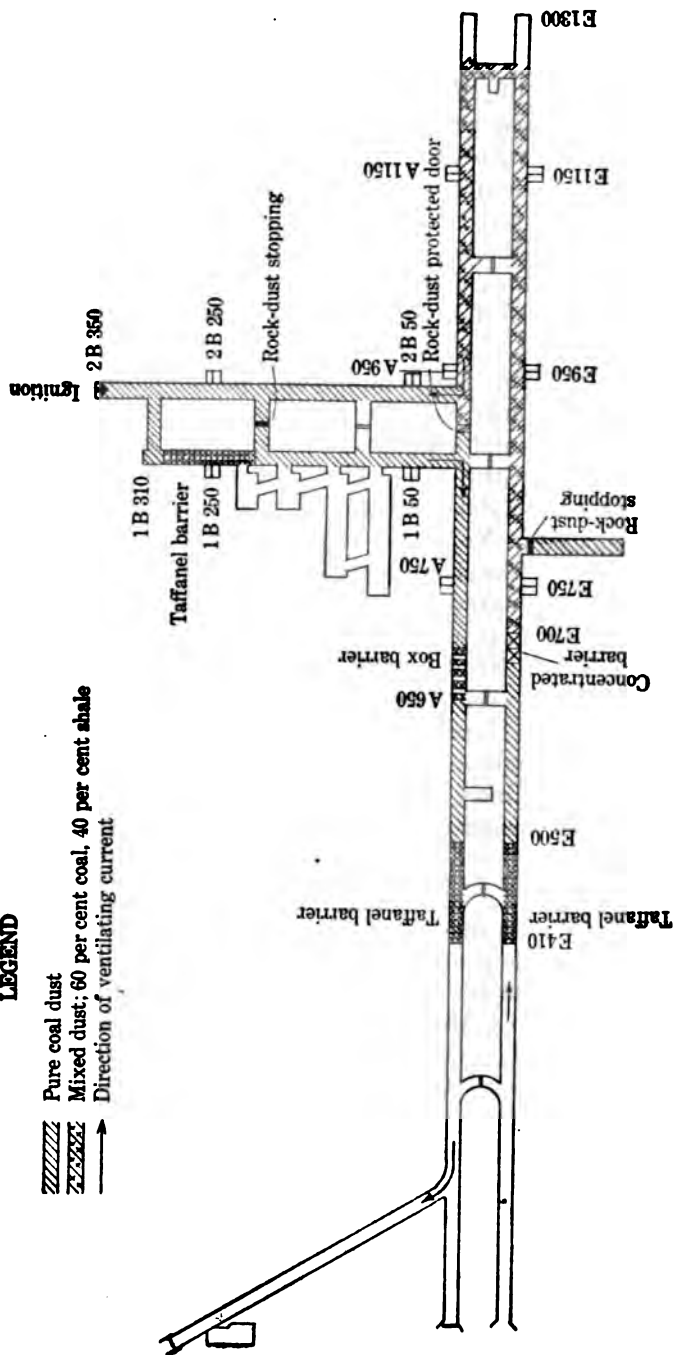


FIGURE 47.—Arrangements of conditions for test 141, October 9, 1914.

barrier. A rock-dust stopping was placed in the right butt turned from the entry at E 775, the entire butt inby the stopping being loaded with pure pulverized Pittsburgh coal dust. A Rice rock-dust-protected ventilating door was placed at A 875. Pure pulverized Pittsburgh coal dust was loaded from A 875 to A 700. A six-box barrier was placed at A 700. Pulverized Pittsburgh coal dust was then loaded to A 500, and a 15-shelf Taffanel barrier was placed at the end of this zone. A rock-dust stopping was placed in the 200 cut-through between No. 1 and No. 2 butts. A 15-shelf Taffanel barrier was placed in No. 1 butt from 1B 295 to 1B 205. No. 1 butt was loaded with pure pulverized Pittsburgh coal dust outby the Taffanel barrier.

The explosion was successfully originated at the face of No. 2 butt, traveled out No. 2 butt, thence inby in the air course toward the face through the cut-through and out the entry to E 700, all side branches therefrom being protected by various types of barriers. Every main barrier had a zone of pure pulverized Pittsburgh coal dust outby in order to make sure if any flame passed beyond. If flame would pass through the barrier this auxiliary zone would be ignited and a further extension of the explosion would result.

The explosion produced moderate pressures in the butt entry but built up considerable pressure in the main entry after traveling about 1,200 feet, the pressure at station E 750 being about 40 pounds per square inch. All of the barriers operated and the flame was confined to the path originally intended for it. Most of the barriers were entirely destroyed by violence. The test was entirely successful as a demonstration of the operation of various explosion-stopping devices. Reference to this will be made again in the chapter on barriers.

THIRD TEST.

A third test (No. 148) was made in No. 2 butt on December 4, 1914. This test was made to try out a proposed device for stopping explosions, which had been referred to the Bureau of Mines for examination and test.

The patented device consisted of screen doors hinged from the roof and held up by a wire running over pulleys to an iron socket containing four detonators and some black powder. A tin funnel was directed toward the black powder. Any flame was supposed to be directed toward the black powder and detonators. By the ignition of these the socket and wire would be broken and the screen doors caused to drop across the entry, the screens preventing passage of flame. An auxiliary aid for extinguishing the flames was a tank containing water and carbonate of soda and having at the top a bottle of sulphuric acid to be broken by a falling weight, also attached by wire to the socket

containing the detonator. The breaking of the bottle and the liberation of acid would cause rapid formation of carbon dioxide and hence pressure, expelling the water and carbon dioxide through a sprinkle head.

The explosion was originated by a standard blown-out shot at the face of No. 2 butt entry and the detonator socket and funnel faced the cannon. One screen door was placed across the last open cut-through and one across the butt entry 126 feet from the shot. Pure pulverized Pittsburgh coal dust was loaded in No. 2 butt and the two open cut-throughs to No. 1 butt. A six-box barrier was installed at A 700 and a four-box barrier at A 915, the second box barrier being in by No. 2 butt. A rock-dust stopping was placed in the 200 cut-through to No. 1 butt, and a 10-shelf Taffanel barrier was placed in No. 1 butt just outby the last cut-through, a second Taffanel barrier being installed in the mouth of No. 1 butt.

The resulting explosion was not stopped by the devices under test, and probably they had no effect on its development, the flame extending past both the screen doors, which were rolled up into balls. However, although the flame went 224 feet beyond the screen door in the butt, it died out when it reached the air course. The sprinkling tank was thrown down some distance from its former position. The tank was empty, but it is not known whether the contents were discharged at the moment of the explosion or subsequently.

CONCLUSIONS FROM RESULTS OF THE THREE TESTS.

It will be observed that in none of these three tests were high pressures and velocities obtained^{44a}, although pure pulverized Pittsburgh coal dust was used. The reason is not evident. The conditions are similar to those for single-entry tests originating at the face of the main entry, in the following points: The zone is 350 feet long; the igniting zone is 50 feet in advance of the cut-through; there is a parallel entry connected by the last cut-through. The testing conditions differ from those in the main entry in that two cut-throughs to the parallel entry were open, that rooms were turned off of the parallel entry, and that the entry in which the explosion originated squarely faced a blank wall. It is thought that closing the second open cut-through would not materially affect results, because in later tests the closing of both cut-throughs did not give high pressures and velocities with mixed pulverized dusts. The principal factor appears to be that the explosion is faced by a solid wall at the end of the 350-foot zone, whereas the main entries, which are straight to their entrances, offer no facing walls to set up reflecting waves. It has been conjectured that this is one of the reasons why a violent explosion was not obtained in No. 2 butt.

^{44a} Except in test 141, the explosion developed strongly after entering the main entry.

Further evidence on this point is given by later tests in No. 1 and No. 2 butts. An explosion originating at the face of No. 1 butt would usually turn the corner at A 850 and continue out the air course. No. 1 butt faces into the closed cut-through between the air course and the entry. Thus, instead of the explosion facing a blank wall, it impinges on an air cushion having an area which is the same as that of the butt and a length of about 20 feet. The evidence on these points is not complete nor satisfactory, so it is the intention to investigate these matters in future tests.

EXPLOSION TESTS TO DETERMINE THE COMPARATIVE EFFECTS OF WEAK AND OF STRONG STOPPINGS ON AN EXPLOSION.

In the consideration of coal-dust explosions the argument has been advanced frequently that if the pressure developed by an explosion is relieved near the origin, before the explosion has had a chance to develop, air movements will not be rapid enough to raise dust in advance of the flame in a sufficiently dense cloud to continue explosive combustion; thus the explosion will be automatically extinguished. Some indication of this was observed in the early tests in the entry in which no loading was present in the cut-through and in the air course. Considerable difficulty was experienced in these tests in obtaining uniform results. Later tests in which the cut-through and the air course were loaded gave much higher explosibility limits and seemed to confirm the view that the relief of pressure along the air course considerably retarded the development of the explosion. The point has been frequently raised that if in an actual mine explosion the stoppings were of light construction and were destroyed by the first pressure wave the pressure would be relieved and the explosion would not propagate. An objection to this was that, on the other hand, the destruction of the stoppings might open up fresh areas in the parallel entries and more rooms for the explosion to travel through, so that it perhaps reaches parts of the mine and groups of men not otherwise endangered. Moreover, if the stoppings in a mine are all thrown down by an explosion, to recover the mine it would be necessary to reerect hundreds of stoppings. In order to obtain some definite information on this matter 16 tests were run in the butt entries of the experimental mine.

DESCRIPTION OF BUTT ENTRIES AND CONSTRUCTION OF STOPPINGS.

At the time of running these tests the butt entries, measured from the center line of the air course, were 350 feet long. Cut-throughs connecting them had been driven every 100 feet, the last being 50 feet from the face. The first cut-through from the air course

had a reinforced concrete stopping in it. This stopping was of the same type as those installed in the cut-throughs between the entry and the air course. The second and third cut-throughs were purposely left open for the testing of various types of stoppings. In order to obtain the desired information, tests were run with the 200 and 300 cut-throughs in three different conditions.

(1) No stoppings present.

(2) Light stoppings present, these being of such construction that the advance air wave would destroy them.

(3) Plank stoppings installed in such a way as to be unaffected by the pressure of an initiatory explosion.

The light stoppings were constructed of 1-inch boards nailed to 4-inch by 4-inch posts, the posts being wedged in an upright position in the cut-through. After the stopping had been constructed the cracks were plastered with mud made from the shale dust used in barriers, thus making the stopping airtight.

The strong stoppings were made by setting three 8-inch by 8-inch timbers horizontally in vertical grooves dug in the ribs. Two-inch planks were nailed on these vertically. This stopping was reinforced in the center of the back by a vertical 8-inch by 8-inch timber wedged in place. Three sets of 6-inch by 8-inch bracing timbers about 7 feet 6 inches long extended from this vertical timber to recesses cut in the rib. Plate XII, *B* (p. 65), shows the details of construction of this stopping.

GENERAL DESCRIPTION AND RESULTS OF TESTS.

The tests of this series were similar to the standard propagation tests run in the main entries. The cannon was situated at the face of one of the butt entries and was loaded with a standard charge of black powder and clay stemming. Pulverized Pittsburgh coal dust was distributed from the face of the butt to the first (or 300-foot) cut-through, a distance of 50 feet, in the same manner as for propagation tests in the entry. Mixed dust was then distributed either in one or both butts, as was necessary for the test, at the rate of 2 pounds of coal dust per foot in the butt entry in which the igniting shot was fired and 1 pound per foot in the other butt entry and in the two cut-throughs.

The originating shot was at the face of No. 2 butt in eight tests and at the face of No. 1 butt in eight additional tests. The purpose of this was to determine, if possible, the effect of the presence of the rooms driven off of No. 1 butt in giving additional relief of pressure. Standard pulverized Pittsburgh coal dust and standard pulverized pit-shale dust were used in three of the tests in No. 2 butt and two of the tests in No. 1 butt. Standard 20-mesh (10 per cent 200-mesh)

Pittsburgh coal dust and 20-mesh shale dust were used in five of the tests in No. 2 butt and six of the tests in No. 1 butt.

The butt entries were cleaned as thoroughly as possible for these tests by sweeping them with brooms and blowing them with a jet of compressed air. The ribs and roof were what would be considered clean in ordinary mining practice and the fine loose material was removed from the floor. In a few places loose lumps were left on the floor, but these were entirely too large to have any influence on the explosion, being mostly pieces of "draw slate" which had been used as ballast. The dust was largely distributed on cross shelves and on the floor, there being no side shelves installed in the butts except in the first 50 feet from the cannon. In this 50-foot zone the pulverized Pittsburgh coal dust was loaded in a manner similar to that in the ignition zone in the entry. The results of these tests are given in Table 44.

TABLE 44.—Results of tests to determine the effect of weak and strong stoppings on an explosion.

[Originating cause: Standard blown-out shot from cannon. Standard ignition zone: 50 feet of pulverized Pittsburgh coal dust immediately outby igniting shot. Pittsburgh coal and pit shale was used in preparing the mixed dusts for these tests.]

MIXTURES OF PULVERIZED COAL DUST AND PULVERIZED SHALE DUST.

[Point of origin: 2B 350.]

Test No.	Date.	Mixed-dust loading.				Stoppings in 200 and 300 cut-throughs.	Records at stations in—	Pressure.		Time of tin-foil rupture at stations and flame velocity between stations.					Length of flame in mixed-dust zone.	Remarks.
		Ratio of coal dust to shale dust in mixture.	Zone.	Rate of loading.	Amount.			Station 250.	Station 50.	Foil at station 250.	Foil at station 50.	Foil at station 50.	Foil at station 50.	Foil at station 50.		
425	May 8, 1917	30:70	{2B 300 to 2B 0. 2B 300 to 1B 0. 200 cut-through..	Lbs. per ft.	Pounds.	{None..... {1 butt.	{2 butt. {1 butt.	Lbs. per sq. in.	Lbs. per sq. in.	Sec. onds.	Sec. onds.	Sec. per sec.	Sec. onds.	Sec. onds.	Fed. (a)	
				6.67 3.33	{2,000 1,333 3,333			2 2	2	0.783 1.500	2.378			125		
426	May 9, 1917	30:70	{2B 300 to 2B 0. 2B 300 to 1B 0. 200 cut-through..	6.67 3.33	{2,000 1,333 3,333	{Light board stoppings.	{2 butt. {1 butt.	1 2	2	.722	113	2.495			(a) 125	
430	May 21, 1917	30:70	{2B 300 to 2B 0. 2B 300 to 1B 0. 200 cut-through..	6.67 3.33	{2,000 1,333 3,333	{Heavyboard stoppings.	{2 butt. {1 butt.	4 1	2 1	.445	c. 254				(a) None.	

[Point of origin: 1B 350.]

466 ^b	Mar. 18, 1918	30:70	1B 300 to 1B 0... 300 cut-through. 200 cut-through.	6.67 3.33	2,000 667 2,667	None..... (1 butt. 2 butt.	2 2	2 2	1.079 1.620	75	3.742	195	4.491	(^a) 150	{Propagation obtained in No. 1 butt. Flame extended 250 feet outby No. 1 butt. No flame inby No. 1 butt.
464	Mar. 11, 1918	25:75	1B 300 to 1B 0...	4.00	1,200	Heavy board { stoppings.	1 1	1 1	.687					225 0	{Propagation not ob- tained.

MIXTURES OF 20-MESH, 10 PER CENT 200-MESH, COAL DUST AND 20-MESH SHALE DUST.

[Point of origin: 2B 350.]

429	May 17, 1917	70:30	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	2.86 1.43	857 571 1,428	None..... (2 butt. 1 butt.	2 2	2 2	0.452 .659	94	2.583	85	3.941	(^a) 150	{Propagation obtained in No. 2 butt. Flame extended 50 feet outby and 75 feet inby No. 3 butt.
428	May 15, 1917	60:40	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	3.33 1.67	1,000 667 1,667	None..... (2 butt. 1 butt.	2 2	2 2	.884 .742	36	6.367			250 150	{Propagation not ob- tained.
459	Feb. 27, 1918	60:40	2B 300 to 2B 0...	3.33	1,000	Heavy board { stoppings.	3 2	2 2	.455	225	1.342	65	2.947	(^a) None.	{Propagation obtained in No. 2 butt. Stop- page not affected. Flame extended 200 feet outby and 75 feet inby No. 2 butt.
427	May 14, 1917	50:50	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	4.00 2.00	1,200 800 2,000	None..... (2 butt. 1 butt.	1 1	1 1	.776					150 75	{Propagation not ob- tained.
460	Mar. 1, 1918	50:50	2B 300 to 2B 0...	4.00	1,200	Heavy board { stoppings.	2 1	2 2	.733	153	2.039	61	3.747	(^a) None.	{Propagation obtained in No. 2 butt. Stop- page not affected. Flame extended 175 feet outby and 50 feet inby No. 3 butt.

^a Flame extended through zone. ^b Flame velocity and pressure curves of tests 466 shown in figure 76. ^c Foil evidently broken by shock wave in advance of flame.

TABLE 44.—Results of tests to determine the effect of weak and strong stoppings on an explosion.

[Originating cause: Standard blown-out shot from cannon. Standard ignition zone: 50 feet of pulverized Pittsburgh coal dust immediately outby igniting shot. Pittsburgh coal and pit shale was used in preparing the mixed dusts for these tests.]

MIXTURES OF PULVERIZED COAL DUST AND PULVERIZED SHALE DUST.

[Point of origin: 2B 350.]

Test No.	Date.	Mixed-dust loading.				Pressure.		Time of tin-fall rupture at stations and flame velocity between stations.					Remarks.
		Ratio of coal dust to shale dust in mixture.	Zone.	Rate of loading.	Amount.	Stoppings in 200 and 300 cut-throughs.	Records at stations in—	Sta- tion 250.	Sta- tion 50.	Fall at Ve- locity 250.	Fall at Ve- locity 50.	Fall at Ve- locity.	
425	May 8, 1917	30:70	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through..	Lbs. per ft.	Pounds.	None..... { 2 butt. { 1 butt.		Lbs. per sq. in.	Lbs. per sq. in.	Fed. per sec.	Sec. onds.	Fed. per sec.	Fall at Ve- locity.
				6.67	2,000			2	2	125	.....	.....	.....
				3.33	1,333			2	2	125	.....	.....	.....
426	May 9, 1917	30:70	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through..	6.67	2,000	Light board stoppings. { 2 butt. { 1 butt.		1	2	113	2.485	.....	.....
				3.33	1,333			2	2	.....	.....	.....	.....
				.....	3,333			.....	.....	.....	.....	.....	.....
420	May 21, 1917	30:70	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through..	6.67	2,000	Heavyboard stoppings. { 2 butt. { 1 butt.		4	2	.....	.....	.....	.....
				3.33	1,333			1	1	.....	.....	.....	.....
				.....	3,333			.....	.....	.....	.....	.....	.....

Flame extended 50 feet outby and 25 feet inby No. 2 butt. Propagation was in- complete in No. 1 butt.

Flame extended 25 feet outby and 50 feet inby No. 2 butt. Propagation was in- complete in No. 1 butt. Stoppings were blown out.

Flame reached station A 550. Velocity be- tween 2B 250 and A 550 was 110 feet per second. Stop- pings were not dis- turbed. Flame ex- tended 375 feet out- by and 125 feet inby No. 2 butt.

[Point of origin: 1B 350.]

460 ^a	Mar. 18, 1918	30:70	1B 300 to 1B 0... 300 cut-through, 200 cut-through.	6.67 3.33	2,000 667 2,667	None.....	1 butt. 2 butt.	2 2	2 2	1.079 1.620	75 3.742	195 4.491	(^a) 150	Propagation obtained in No. 1 butt. Flame extended 250 feet outby No. 1 butt. No flame inby No. 1 butt.
464	Mar. 11, 1918	25:75	1B 300 to 1B 0...	4.00	1,200	Heavy board stoppings.	1 butt. 2 butt.	1 1	1 1	.687			225 0	Propagation not ob- tained.

MIXTURES OF 20-MESH, 10 PER CENT 200-MESH, COAL DUST AND 20-MESH SHALE DUST.

[Point of origin: 2B 350.]

429	May 17, 1917	70:30	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	2.86 1.43	857 571 1,428	None.....	2 butt. 1 butt.	2 2	2 2	0.452 .659	94 2.583	85 3.941	(^a) 150	Propagation obtained in No. 2 butt. Flame extended 50 feet outby and 75 feet inby No. 2 butt.
428	May 15, 1917	60:40	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	3.33 1.67	1,000 667 1,667	None.....	2 butt. 1 butt.	2 2	2 2	.884 .742	36 6.367		250 150	Propagation not ob- tained.
459	Feb. 27, 1918	60:40	2B 300 to 2B 0...	3.33	1,000	Heavy board stoppings.	2 butt. 1 butt.	3 2	2 2	.455	225 1.342	65 2.947	(^a) None.	Propagation obtained in No. 2 butt. Stop- pings not affected. Flame extended 200 feet outby and 75 feet inby No. 2 butt.
427	May 14, 1917	50:50	2B 300 to 2B 0... 2B 300 to 1B 0... 200 cut-through.	4.00 2.00	1,200 800 2,000	None.....	2 butt. 1 butt.	1 1	1 1	.776			150 75	Propagation not ob- tained.
460	Mar. 1, 1918	50:50	2B 300 to 2B 0...	4.00	1,200	Heavy board stoppings.	2 butt. 1 butt.	2 1	2 2	.733	153 2.039	61 3.747	(^a) None.	Propagation obtained in No. 2 butt. Stop- pings not affected. Flame extended 175 feet outby and 50 feet inby No. 2 butt.

^a Flame extended through zone. ^b Flame velocity and pressure curves of tests 466 shown in figure 76. ^c Foil evidently broken by shock wave in advance of flame.

TABLE 44.—Results of tests to determine the effect of weak and strong stoppings on an explosion—Continued.

MIXTURES OF 20-MESH, 10 PER CENT 200-MESH, COAL DUST AND 20-MESH SHALE DUST—Continued.

[Point of origin: 1B 350.]

Test No.	Date.	Mixed-dust loading.				Stoppings in 200 and 300 cut-throughs.	Records at stations in—	Pressure.		Time of tin-foil rupture at stations and flame velocity between stations.					Length of flame in mixed-station dust zone.	Remarks.
		Ratio of coal dust to shale dust in mixture.	Zone.	Rate of loading.	Amount.			Station 250.	Station 30.	Fall at station 250.	Velocity.	Fall at station 30.	Velocity.	Fall at station 250.			Velocity.
465	Mar. 13, 1918	70:30	1B 300 to 1B 0... 1B 300 to 2B 0... 200 cut-through.	Lbs. per ft. 2.86 1.43	Pounds. 857 572 1,429	{ None..... (1 butt. (2 butt.	Lbs. per sq. in. 2 2	Lbs. per sq. in. 2 2	Sec-onds. 0.417 1.440	Fet per sec. 3.904	Sec-onds. 3.407	Fet per sec.	Sec-onds.	Fet.	(a) 125	{ Propagation obtained in No. 1 butt. Flame extended 175 feet outby No. 1 butt, but there was no flame inby this butt. Flame velocity from 1B 250 to A 750 was 115 feet per second.
461	Mar. 5, 1918	70:30	1B 300 to 1B 0...	2.86	857	{ Heavy board stoppings. (1 butt. (2 butt.	1 1	2 1	.907 5.102	89	3.154	108	4.514	(a)	75	{ Propagation obtained in No. 1 butt. Stopping in 300 cut-through failed. Flame extended 125 feet outby No. 1 butt; no flame inby.
467	Mar. 18, 1918	60:40	1B 300 to 1B 0... 200 and 300 cut-throughs.	3.33 3.33	1,000 333 1,333	{ None..... (1 butt. (2 butt.	2 2	2 2	.893 3.993	97	2.917	95	4.556	(a)	100	{ Propagation obtained in No. 1 butt. Flame extended 175 feet outby No. 1 butt; no flame inby.

402	Mar. 7, 1918	6:40	1B 300 to 1B 0...	3.33	1,000	{ Heavy board stoppings.	{ 1 butt. 2 butt.	1 1	1 1	1 1	1 1	3.832 3.778	3.802	(a) None.	{ Propagation obtained in No. 1 butt. Stop- pings not affected. Flame extended 225 feet outby No. 1 butt; no flame inby.
408	Mar. 20, 1918	50:50	{ 1B 300 to 1B 0... 200 and 300 cut- throughs.	4.00 4.00	{ 1,200 400 1,000	{ None..... Heavy board stoppings.	{ 1 butt. 2 butt.	1 2	2 2	2 2	2 2	2.741 2.254	200 100	(a) None.	{ Propagation not ob- tained.
403	Mar. 8, 1918	50:50	1B 300 to 1B 0...	4.00	1,200	{ Heavy board stoppings.	{ 1 butt. 2 butt.	1 1	1 1	1 1	1 1	1.207 2.417	100 3.866	(a) None.	{ Propagation obtained in No. 1 butt. Stop- pings not affected. Flame extended 160 feet outby and 25 feet inby No. 1 butt.

* Flame extended through zone.

DETAILS OF THE TESTS AND DISCUSSION OF RESULTS.

MIXTURES OF PULVERIZED PITTSBURGH COAL DUST AND PULVERIZED
PIT-SHALE DUST.

TESTS WITH ORIGIN IN NO. 2 BUTT.

In test 425 a mixture of 30 per cent pulverized coal dust and 70 per cent shale dust was distributed throughout No. 2 butt, No. 1 butt, and the 200 and 300 cut-throughs, these cut-throughs being left open. The flame propagated through the mixture in No. 2 butt with low velocities and pressures and extended into the air course in both directions, 50 feet outby and 25 feet inby. The flame also turned through the 300 cut-through into No. 1 butt entry and extended outby in that entry.

In test 426 the same mixture of 30 per cent pulverized coal dust and 70 per cent shale dust was used. Light board stoppings installed in the two open cut-throughs were thrown down by the explosion, which had the same characteristics as when there was no stopping. The flame extended through No. 2 butt and 25 feet outby and 50 feet inby in the air course; it also passed through the 300 cut-through and traveled 75 feet outby in No. 1 butt. The pressures in this test were also low (see Table 44).

Comparison of the results of tests 425 and 426 shows that the extent of the flame was practically identical and the rate of travel differed only slightly. The difference is not more than is ordinarily obtained with exactly similar explosion tests. It would appear, therefore, from these two tests that the light stopping did not essentially modify the explosion.

Test 430 was also run with a mixture of 30 per cent pulverized coal dust and 70 per cent shale dust. Strong stoppings were installed in both the 200 and the 300 cut-throughs. The resulting explosion did not damage the stoppings. The flame was prevented from spreading to No. 1 butt and the pressure was retained in No. 2 butt. As a result slightly higher pressures were recorded in this test than in either test 425 or 426 and the flame traveled somewhat more rapidly. The flame extended from No. 2 butt into the air course in both directions, 375 feet outby and 125 feet inby. Comparison of this with test 425 shows that the length of flame had been extended considerably by the presence of the stoppings. Essentially the test was conducted in a single entry 350 feet in length.

TESTS WITH ORIGIN IN NO. 1 BUTT.

In test 466 a mixture of 30 per cent pulverized coal dust and 70 per cent shale dust was distributed throughout No. 1 and No. 2 butts and the 200 and 300 cut-throughs, the igniting shot being placed at the face of No. 1 butt. The pressures in the resulting explosions were low.

The flame traveled out No. 1 butt and 250 feet outby in the air course, but not inby. The flame also went through the 300 cut-through into the No. 2 butt and traveled 100 feet outby in this butt.

In test 464 the strong stoppings were installed and a mixture of 25 per cent pulverized coal dust and 75 per cent shale dust was used. In this test the flame did not reach the air course, stopping 75 feet short. The stoppings held, and the explosion was confined to No. 1 butt.

In comparing the last two tests in the different butt entries it will be noted that these differences existed: In the No. 2 butt, which has no rooms off it, a mixture of 30 per cent coal and 70 per cent shale was used. In the No. 1 butt test the mixture was, through a misunderstanding, made weaker, in fact practically the limiting mixture (25 per cent coal dust and 75 per cent shale dust), and this entry had four rooms off it, permitting relief of pressure. The tests were therefore inconclusive. They will be repeated when the butt entries are extended and more cut-throughs and stoppings enter into the conditions of testing.

MIXTURES OF 20-MESH (10 PER CENT 200-MESH) PITTSBURGH COAL DUST AND 20-MESH PIT-SHALE DUST.

TESTS WITH ORIGIN IN NO. 1 BUTT.

In test 429 a mixture of 70 per cent 20-mesh coal dust and 30 per cent 20-mesh shale dust was distributed throughout No. 2 and No. 1 butts and the 200 and 300 cut-throughs. No stoppings were used. Propagation through No. 2 butt was obtained with low pressures and velocities, the flame extending 50 feet outby and 75 feet inby in the air course. The flame also turned through the 300 cut-through and traveled 100 feet down No. 1 butt.

In test 428 a mixture of 60 per cent 20-mesh coal dust and 40 per cent shale dust was distributed in both butts and in the cut-throughs, no stoppings being used. A weak explosion resulted, the flame traveling down No. 2 butt to within 50 feet of the air course, where it stopped. It also turned through the 300 cut-through and traveled 100 feet outby in No. 1 butt.

In test 459 a mixture of 60 per cent 20-mesh coal dust and 40 per cent shale dust was used. Strong stoppings were placed in the cut-throughs. The flame traveled out No. 2 butt and 200 feet outby and 75 feet inby in the air course. The stoppings were not affected.

In test 427 a mixture of 50 per cent 20-mesh coal dust and 50 per cent shale dust was distributed through the two butts and the open cut-throughs, no stoppings being used. The resulting explosion was very weak, the flame traveling only 150 feet in No. 2 butt and 25 feet in No. 1 butt after passing through the 300 cut-through. This mixture would give propagation in the standard entry tests,

indicating that the conditions in the butt entries are slightly less severe.

In test 460 the mixture of 50 per cent 20-mesh coal dust and 50 per cent shale dust was again used, but with strong stoppings in the cut-throughs. The explosion traveled out No. 2 butt with low pressures and velocities and extended 175 feet outby and 50 feet inby in the air course. The stoppings were not damaged and the explosion did not enter No. 1 butt. Comparison of these tests indicates that the placing of the strong stoppings in all cut-throughs caused propagation of an explosion in a mixture which would not propagate with the cut-throughs open. However, such a conclusion would be premature, as the use of a strong stopping in the cut-through nearest the face gives a condition not found in ordinary coal-mining operations.

TESTS WITH ORIGIN IN NO. 1 BUTT.

In test 465 a mixture of 70 per cent 20-mesh coal dust and 30 per cent shale dust was distributed throughout the No. 1 and No. 2 butts and the two open cut-throughs, no stoppings being used. The resulting explosion traveled out No. 1 butt and 175 feet outby in the air course. The flame turned through the 300 cut-through and traveled 75 feet out No. 2 butt.

In test 461 the 70 per cent 20-mesh coal dust and 30 per cent shale dust mixture was tested with the strong stoppings in place. The stopping in the 300 cut-through had been braced to withstand explosions coming down No. 2 butt, and upon being subjected to an explosion from No. 1 butt was partly thrown down, some of the 2-inch planks being torn off. The flame traveled out No. 1 butt and 125 feet outby in the air course. It also turned through the 300 cut-through and traveled outby in No. 2 butt. The pressures and extent of the explosion were very similar to those of test 465, the flame being slightly shorter.

In test 467 a mixture of 60 per cent 20-mesh coal dust and 40 per cent shale dust was distributed throughout the two butts and the two cut-throughs, no stoppings being used. The flame traveled out No. 1 butt and 175 feet outby in the air course; it also turned through the 300 cut-through but traveled only 50 feet outby in No. 2 butt. The pressures and velocities with this less sensitive mixture were low, but the explosion extended through the whole length of the No. 1 butt despite both cut-throughs and rooms giving opportunity for relief, whereas in the No. 2 butt the same mixture failed to propagate the explosion. Apparently, therefore, other factors than side openings were more important in causing propagation. It is thought that one of these factors is that the No. 2 butt squarely faces a coal rib from which shock waves may reflect and interfere with advance movements.

In test 462 a mixture of 60 per cent 20-mesh coal dust and 40 per cent shale dust was again used with strong stoppings in place. The resulting pressures were low. The flame traveled out No. 1 butt and 225 feet outby in the air course; thus essentially the same results were obtained as in the previous test with no stoppings.

In test 468 a mixture of 50 per cent 20-mesh coal dust and 50 per cent shale dust was distributed throughout the two butts and the cut-throughs, no stoppings being used. The resulting explosion traveled 200 feet into the mixed dust in No. 1 butt, the flame also turning through the 300 cut-through and traveling 50 feet down No. 2 butt.

In test 463 the mixture of 50 per cent 20-mesh coal dust and 50 per cent shale was used with strong stoppings in place. The flame traveled out No. 1 butt and 150 feet outby and 25 feet inby in the air course.

By comparison of these tests in the No. 1 butt with those originated in No. 2 butt entry it will be observed that the explosion results were much the same.

With open cut-throughs an explosion in the 60 per cent coal dust and 40 per cent shale dust mixture stopped 50 feet short of the air course when originated in No. 2 butt, but gave complete propagation when originated in No. 1 butt. The difference, however, is too slight to form the basis of any conclusions. The 50 per cent coal dust and 50 per shale dust mixture gave propagation in either entry with strong stoppings in place. The explosibility limits are about the same as obtained in tests with double-entry zones.

CONCLUSIONS FROM RESULTS OF THE TESTS.

In reviewing the whole series the effect of weak stoppings or open cut-throughs as compared with that of strong stoppings placed in every cut-through, thus converting the entry into a single gallery is as follows: With the strong stoppings shale dust in slightly larger amounts must be added to the mixture to make it nonpropagating.

The closing of the last stopping is, however, a special case, the equivalent in ordinary mining being the opening of a new mine, where long distances between cut-throughs or crosscuts are permitted. Only a tentative conclusion can be drawn, until the butt entries have been driven further and more cut-throughs brought into the testing. The tentative conclusion based on these tests is that a lack of stoppings or weak stoppings are not of value in preventing the starting of an explosion. This conclusion, from the comparative tests with and without strong stoppings, is fortified by the rather surprising result found—that it is easier to obtain propagation through the No. 1 butt entry with open rooms off it than in the No. 2 butt with no rooms. It is complicated, however, by the possible effect mentioned above—

that the coal rib squarely facing the mouth of the No. 2 butt may reflect interfering pressure waves. In either case, rock-dust barriers in open cut-throughs or those with weak stoppings would be most valuable in arresting explosions that might penetrate other entries or rooms. Nothing was disclosed by these tests that would lead to abandoning the use of strong stoppings in the hope of preventing the propagation of explosions once started. To render coal dust inert is the only final solution.

STRENGTH OF PERMANENT STOPPINGS IN EXPERIMENTAL MINE.

In reviewing the problem of mine stoppings—both in its bearing on the question of weak versus strong stoppings, and on the selection of the type of stoppings to be generally employed in mining—consideration should be given to the strength of the permanent stoppings used in the experimental mine.

All the cut-throughs between the main entries (except the open one nearest the faces at E-A 1250), and between the butt entries have had stoppings of massive construction in them during the entire series of tests following enlargement of the mine. These stoppings were built of concrete, reinforced by a grillage of steel bars on each side; the horizontal reinforcement being $\frac{3}{4}$ -inch round bars with 4 inches spacing center to center, and the vertical reinforcement being $\frac{1}{2}$ -inch square bars with 18 inches spacing. The stoppings were formed into the sides in deep 1-foot grooves cut into the coal, and were also keyed to the limestone floor and the roof, by bars set in drill holes. The stoppings were about 18 inches thick, about $6\frac{1}{2}$ feet high, and 8 feet wide, not including what was cast into the 1-foot grooves in the coal. The two stoppings in the curved cut-through at E-A 250 and 450, respectively, had slightly heavier reinforcement.

FAILURE OF A CONCRETE STOPPING.

The standard construction is indicated in the photograph of the one stopping that failed (Pl. II, *A* and *B*, p. 36). That was the only failure of this type of stopping in over 400 explosion tests, in some of which the recorded momentary static pressures at the nearest monometric station (in the ribs of the entry 100 feet from the respective cut-throughs) were over 110 pounds per square inch, in one test 127 pounds. There were probably instances in which the pressures in the entry opposite the stopping exceeded even the latter; but as the distance from the corner of the entry to the stopping is 18 feet and no coal-dust loading is placed in the cut-through, the pressure transmitted to the stopping may be materially less. On the other hand, in some of the explosions there was a surplus of coal dust, and if the swirling air currents ahead of the explosion carried dust

into the cut-through, then the stopping might experience pressure from the kinetic energy of the explosion.

The standard permanent stoppings were designed to have an ultimate or breaking strength for a pressure of over 50 pounds per square inch applied over the exposed face on either side of the stopping.

The stopping that failed was in cut-through 650, just half way between the mouth of the mine and the face. It was the only one that had a small iron door placed centrally. Cracks first developed in test 46 when there were registered pressures of 55 pounds per square inch at station E750, 100 feet inby, and 120 pounds at station E550, 100 feet outby the cut-through—an average of 87 pounds. The cracks enlarged in tests 52, 54, 55, 65, and 66, in which the static maximum pressures at the neighboring stations ranged from 48 to 73 pounds per square inch. In test 66 the stopping was badly cracked around the door frame and the steel plate door bulged toward the air course. The maximum pressure registered in this test was 64 pounds per square inch at E750.

In test 67 the stopping entirely failed, shearing at the outby rib and swinging around toward the air course, like a door, hinged by the reinforcement at the inby rib. (See Pl. II B.) The maximum recorded pressure in this test at station E750 was 50 pounds.

In the tests from No. 55 to No. 67 there was a rock dust barrier opposite the 650 cut-through, which caused the pressure at the outby station 550 to be much lower, but the maximum pressure at E650 was undoubtedly higher than at E750 in these tests. Weighing all the evidence, it seems probable that the stopping was subjected to pressures in excess of 60 pounds and not improbably in excess of 75 pounds per square inch before yielding.

It is expected that direct evidence of the pressures to which the stoppings are subjected under the specified conditions of location and dust loading will be obtained by future testing.

FAILURE OF BRICK STOPPING.

When the main entries were extended to their present length, and the concrete stoppings were put in most of the cut-throughs, a brick stopping, recessed in grooves in the ribs, was put in the 850 cut-through; it was a solid brick wall 18 inches thick laid in cement mortar. In test 20, a violent explosion, this stopping was thrown down, some pieces of the brick masonry were hurled 235 feet into No. 1 butt which was opposite, and some carried 150 feet outby in the air course. The manometric pressure at the nearest instrument, at E550, 250 feet outby, showed a pressure of 34 pounds per square inch. Judged from the general relation of the recorded pressures, the static pressure in the entry opposite to the stopping at 850 would have been between 20 and 30 pounds per square inch.

In this same explosion, a braced wooden stopping in the last cut-through at 1250 was also blown down. It is noteworthy that the giving way of two stoppings near the origin of an explosion did not prevent the starting or propagation of a violent explosion in which the pressure rose to 114 pounds per square inch 500 feet outby the brick stopping that was thrown down.

CHAPTER VIII.—PRODUCTION OF COAL DUST IN MINING AND METHODS OF PREVENTING EXPLOSIONS.

As has been repeatedly pointed out by many writers, entire avoidance of the production and distribution of coal dust in mines is not possible, but both the production and distribution, particularly the latter, can be lessened greatly by selecting suitable machinery and by adopting certain devices in transportation.

WAYS IN WHICH COAL DUST IS MADE IN MINES.

AT THE FACE OF THE WORKINGS.

The chief ways in which coal dust is made at the face are as follows:

1. Drilling in coal. Production of dust in this manner is virtually unavoidable, but the quantity is small.

2. Machine cutting. The production of dust from this source in considerable amounts is unavoidable, but can be lessened by the use of sharp bits in the undercutters. The question of the removal of the machine cuttings or "bug dust" is one that has been much debated and practice varies. In some mines the operators permit the cuttings to be loaded with the run-of-mine coal. In other mines the cutting is done in impure coal, and to load such cuttings with the pure coal where there is no washery at the mine would lower the quality and market value of the product. Under these conditions the cuttings are often left in the mine. When the cuttings are left at the face of the workings while shooting is being done, the blast blows back the fine dust, depositing it over the surfaces of the gob. If a long-flame explosive like black blasting powder is used the blast may ignite the dust and start an explosion. One large disaster was thought by investigators of the Bureau of Mines to have been originated in this way.

The best practice as regards safety is to wet the "bug dust" and load it out of the room before blasting. It is important that this dust be wetted before being disturbed, otherwise the finest and most dangerous dust will float off and settle upon all exposed surfaces, making the place more hazardous than before. If it is not feasible for various reasons to send the cuttings out of the mine, they should be piled in the gob far enough from the face not to be directly affected by the shooting and should be covered with pieces of slate or with rock dust.

3. The process of picking the coal by hand, in undercutting and shearing; also the process of blasting.

4. Coal falling from cars and being ground up by the wheels. This is one of the most important sources of coal-dust production in roadways and can be almost wholly avoided by using tight cars without gates and not loading the cars above the sides.

5. The use of broken coal to ballast tracks. This is a reprehensible practice and should not be permitted, inasmuch as the fragments of coal are pulverized in time by the feet of men, horses, and mules. Apart from the increased danger of explosions, such practice is not an economy, as coal is a poor ballasting material.

DISTRIBUTION OF COAL DUST.

Coal dust in isolated piles presents comparatively little danger in the initiatory stage of an explosion, but becomes important when the explosion is once well started as the advance waves will sweep it up into the air. Moreover, when coal dust is once made it is difficult to prevent the dust being distributed by ordinary mine agencies. The following are the chief ways in which coal dust is distributed:

1. Blasting, chiefly blasting at the face. Excessive charges of powder will blow the coal dust into the air, whence it settles over the room gob or is carried into the entries. Distribution in this way is particularly dangerous, as the finest and most sensitive dust is deposited in an even layer on all exposed surfaces.

2. Ventilating currents. This factor is of small importance at the face of workings, as the air velocity is low, but is important in entries in the distribution and deposition of fine float dust on timbers and rib projections.

3. Air eddies from car movements. Such eddies are an important factor in raising and bringing up float dust into the air to be re-deposited later on surfaces.

4. Sifting of coal dust through leaky joints of wooden cars, particularly under the doors or gates of cars. This important source of dust distribution through entries can be prevented by the use of tight cars without end gates, the cars being unloaded by rotary triples.

CONCLUSION REGARDING DUST MAKING AND DISTRIBUTION.

Production of coal dust at the face or in rooms can be lessened. A considerable amount of it can be loaded and sent out of the mine. In entries production can be largely prevented by adequate means. Coal dust can be neutralized by rock-dusting; also by watering it with a hose where the roof and floor do not disintegrate and "swell" from such watering.

SOURCES AND PREVENTIVES OF IGNITION.

As stated in the previous paragraph, it is practically impossible to prevent the formation of coal dust at the working faces of a coal mine, but in the entries its production and distribution is almost wholly avoidable. On account of the small quantity of dust that will propagate an explosion, as shown elsewhere in this bulletin, guarding in every respect against this hazard is important, particularly in mines working friable coal, where even abrasion of the ribs may aid in propagating an explosion that originated at the face. Rib dust has been suspected as taking part in one or more disastrous explosions in the New River field of West Virginia and in a mine in Alabama where the entries had been well watered. The following will summarize the principal methods proposed for preventing the ignition of coal dust in air or the propagation of coal-dust explosions:

It is manifest that if coal dust is not ignited in the air it will not explode. Thus mines free from fire damp and in which explosives are seldom used are practically immune. The longwall mines of northern Illinois have been working 50 years, but have had no coal-dust explosions. It is true that a protecting factor in these mines is that the roads are naturally rock-dusted from the shale roof. Plenty of fresh coal dust occurs at the faces, but practically no fire damp is encountered and explosives are rarely used and only in very small amounts.

SOURCES OF IGNITION.

The sources of ignition of the coal-dust explosions that have occurred in the United States, in the order of their importance, are:

1. Long-flame explosives.
2. Ignition of bodies of fire damp.
 - (a) Ignition of fire damp by open lights.
 - (b) Ignition of fire damp by grounding of electric wires.
 - (c) Ignition of fire damp by explosives.
 - (d) Ignition of fire damp by defective safety lamps or an opened safety lamp.
 - (e) Ignition of gases—methane and distilled hydrocarbon gases—by mine fires.
3. Direct ignition of coal dust in air by electric arcing, as by the "short" from a trolley wire.
4. Direct ignition of coal dust in air by an open lamp or torch.

METHODS OF PREVENTING IGNITION.

Of the causes mentioned, the most important method of preventing coal-dust explosions is the elimination of black blasting powder and the substitution therefor of permissible explosives having a short, quick flame, which have been tested for comparative safety by the Bureau of Mines for use in gaseous and dusty mines. To be classified as "permissible" an explosive must not ignite coal dust alone, an explosive mixture of methane and air alone, or coal dust in the presence of a 4 per cent mixture of methane in air, the explosive being used in quantities and in the manner prescribed by the bureau.^{45b} Absolute safety, however, requires that no explosives be used when the percentage of fire damp in the immediate vicinity exceeds 1 per cent.

The second most frequent cause of explosion—ignition of bodies of fire damp by open lights—can be eliminated almost entirely by the employment of miners' permissible electric cap lamps, oil safety lamps being used only when testing for gas. Probably the next most frequent cause—ignition of fire damp by electric arcing—can be practically done away with (1) by so ventilating the mine that there is no likelihood of any explosive body of gas being present, (2) by not using electric haulage or electric-driven machinery or electric lighting in mines or parts of mines which make explosive gas in appreciable quantity, and (3) by limitations of the use of electricity in any form when gas is discovered in any mine or any part of a mine.

The ignition of fire damp by explosives is inexcusable, as the face should always be carefully examined with a safety lamp for the presence of fire damp before the shot or shots are fired.

Ignition of fire damp by defective safety lamps is fortunately infrequent, but several disastrous explosions have occurred in the United States, in which it has been proved fairly conclusively that the cause was a defective safety lamp or one which had been opened by the fire boss.

The direct ignition of coal dust by electric "shorts," as mentioned elsewhere in this bulletin, was probably the cause of at least two great disasters in the United States; in one of them the evidence was well authenticated, in the other less conclusively authenticated, but short-circuiting was undoubtedly the cause. Fortunately, such instances are rare. The preventive is to make the coal dust in the mine so inert that the wreckage of a trip will not stir up dust sufficient to ignite and propagate an explosion.

As regards the direct ignition of mine dust in air by an open lamp or torch, this is probably of rare occurrence in coal mines, although it has been the cause of a number of violent explosions in gilsonite

^{45b} See Howell, S. P., Permissible explosives tested prior to January 1, 1917: Tech. Paper 162, Bureau of Mines, 1917, pp. 6-7

mines in Oklahoma and Utah. In order to be ignited the dust must be raised in a dense and extensive cloud, so that the dust burning about the flame will create initial pressures sufficient to raise additional dust into the air and thus continue propagation. Instances have been observed in mines of a flame from an open light igniting dust stirred up by a trip of cars, but the evidence in extensive explosions has not been clear. However, inflammations and explosions of coal dust have not infrequently happened in surface handling plants and in plants where pure pulverized coal is being used in furnaces, steam plants, reverberatory furnaces, and revolving cement kilns. The remedy is careful designing of the plant to prevent dust getting into the open air and using care to prevent back-firing. Moreover, open lights and sources of electric arcing or short circuits should be eliminated in those parts of the plant where the air is dusty.

GENERAL METHODS PROPOSED FOR THE PREVENTION OF IGNITION AND PROPAGATION.

A number of different methods for removing coal dust from mines or rendering it inert have been proposed from time to time. These methods and their probable value are discussed in the following paragraphs.

MAKING A MINE DUSTLESS.

The usual methods of making a mine dustless are as follows:

(a) Dry cleaning with shovels and brooms. The shovel is useful in loading out an accumulation of coal dust, but the broom is of doubtful value, as it tends to stir up the finest dust, which settles again elsewhere.

(b) Cleaning with vacuum cleaners. This has been seriously proposed by a number of people and a Scotch manufacturer has developed a machine for the purpose similar to the vacuum cleaner used for domestic purposes. However, the method is not considered entirely practicable on account of the high cost. Judging from tests in the experimental mine, as described elsewhere in this bulletin, the so-called dustless zones would not be a certain barrier for an explosion once started.

(c) Lining the entries with brick or concrete, covering the surfaces with cement, or whitewashing them, so they can be easily cleaned. These methods are admirable for other reasons than for keeping down dust, but it is virtually impossible, on account of the expense, to line all the passages; hence these methods can be considered only auxiliary.

At earlier stages of the investigations abroad and in this country dustless zones were considered, but these were found to be virtually impossible to obtain, according to the testing at the experimental mine.

WETTING THE DUST.

The usual methods of wetting the dust are as follows:

(a) Wetting with a tank car. If the car has a force spray which wets the roof, ribs, and floor, and washes down the dust, the method is a good one if used daily, but merely to allow water to dribble from a tank car along the roadway, as is often the practice, does not furnish adequate protection.

(b) Wetting with a water hose. This is an admirable method, but requires the mine to be piped throughout all the entries. The dust can be thoroughly washed down and with less wastage of water than with tank cars, because the water can be put on more freely at points where it is most needed. This excellent method is required by law in Utah, where water lines and spraying are also required in rooms.

(c) Spreading calcium chloride or other deliquescent salts. These are useful aids in keeping dust wet. The method and tests are described in Bulletin 20 of the Bureau of Mines. The specific tests made in the experimental mine are described herein on pages 405 to 407.

(d) Wetting by fixed water sprinklers. This method has not been found to be efficient. Sprinklers are of advantage only in wetting trips of coal cars at points along the haulage road, where they can be adjusted to operate automatically as the trips pass.

Where there is rope haulage there is no objection to sprinkling the cars automatically, but where there is trolley haulage the method is objectionable on account of wetting the electric locomotive and the motorman. However, the sprinklers could be turned on by hand at small expense, as the man who is usually stationed at the main partings or the trip rider could turn on the spray immediately after the locomotive had passed and turn it off after the last car had gone by. The great advantage of sprinkling is that it washes any coal dust on the top surfaces down into the car and thus prevents the air currents from blowing off the fine dust.

(e) Humidifying the intake air by steam or water sprays. Humidification of the air current to the point of saturation was formerly believed to be in itself a protection against explosions, but experiments at the Pittsburgh gallery and in the experimental mine have shown that saturation of the atmosphere has no practical value for preventing either the starting or the propagating of an explosion. The reason for this is that the amount of water vapor in the atmosphere is so small that the heat absorbed in raising its temperature to that developed by the burning coal dust is insignificant.

Tests were made at the experimental mine on the effect of exposing coal dust to a saturated air current. They are described on pages 401 to 405. It was found that the saturated air deposited practically no water and had little effect upon the moisture content of the dust. In other words, fogging the air with steam or fine spray does not wet the dust

except to a limited degree. However, humidifying the air current, although it does not water the coal dust sufficiently to make the dust nonexplosive, has the virtue of preventing drying of the dust and mine surfaces by air currents of low humidity in cold weather. Moreover, less sprinkling and watering are needed to make the coal dust thoroughly wet throughout the mine.

The method of humidifying with steam jets was discussed in Bulletin 20, published in 1911. Since that time some mines have used the method of warming the intake air with exhaust steam coils and then saturating the air by steam jets in connection with water sprays and blankets. These methods are said to be practicable for saturating the intake air.

It should be borne in mind that the field investigations of the bureau clearly indicate that humidification of the air current must be assisted by direct watering methods in order to make the coal dust nonexplosive.

(f) Applications of rock dust to assist in wetting coal dust. It was noticed in the course of the testing that coal dust mixed with shale dust or limestone dust absorbed water more readily than pure coal dust. In fact, dry coal dust is very difficult to wet; it tends to repel water and will float for indefinite periods on the surface of pools unless there is mechanical mixing such as occurs on roadways. Therefore, where watering methods are employed, strewing rock dust on the surface of passageways is a valuable aid in keeping the mine dust wet and has the further merit of tending to pack the coal dust mechanically.

DRY METHODS OF ROCK DUSTING.

In the course of developments at the experimental mine the determination of the inflammability limits of mixed dust led to the conclusion that one of the best methods of rendering coal dust inert was to apply rock dust. This proposition was first made by Sir William Garforth many years ago as a result of his observations after the explosion in the Altofts mine, and he made the first systematic use of rock dust in this mine for explosion prevention. The British experiments, first in the gallery at Altofts and then at the Eskmeals testing station, and the French, at the Lièven testing station, led to the same conclusion. These investigations have been described in Bulletin 20. Since that time rock dusting has been specifically authorized by the British laws, and the method has been extensively adopted in French mines. In this country the method was first employed in a coal mine in Colorado. Tests were conducted and methods of laying the dust were tried out in two of the mines of the Pittsburgh Coal Co. in cooperation with the Bureau of Mines with successful results as regards the safety and economy of using rock dust as compared with water.^{45c}

^{45c} The plan recently has been adopted in southern Illinois mines and has probably prevented in two instances propagation of local gas explosions.

Watering is, however, impracticable for many coal mines in this country on account of the character of the roof coal or floor, and in these mines rock dusting is the obvious alternative.

Although the bureau does not advocate changing from watering to rock dusting in a mine where the results have shown that the dust is kept wet, it should be pointed out that a number of the most disastrous explosions in this country have occurred in mines which have been considered well equipped with sprinklers, force tank cars, and humidifying methods. Evidently wetting the dust in all parts of the mine was not done enough to prevent the propagation of an explosion.

As yet the use of rock dust has been so limited in this country that it can not be reasonably considered as having been proved to be an absolute protection, but many mines have been using it in Great Britain since 1912 and no extensive coal-dust explosion has been reported. The greatest advantage of rock dust is that every entry can be made safe. Under ordinary conditions a treated entry will remain safe for days or weeks or even months without further treatment, whereas in a mine using the watering method if a single day passes in cold weather without watering the dust it may become dangerous. The use of rock dusting in testing has been touched upon in almost all of the tests described herein for determining the explosibility limits of coal dust. The details of using rock dust as a specific agency follow:

METHODS OF ROCK-DUST TREATMENT.

The two general methods for the use of rock dust are (a) applying rock dust to all surfaces of the area to be treated, and (b) establishing concentrated zones where the rock dust is placed in boxes or barriers that will be automatically dumped by an advancing explosion and will extinguish it. Only the former of these methods will be discussed here, the latter being taken up in subsequent pages. This discussion will also be confined to the treatment of entries, because it is believed that by such treatment an explosion may be prevented from traveling throughout a mine, thereby saving the lives of all in the mine except those in the immediate neighborhood of the origin.

Methods for the prevention of explosions in rooms and at the working faces present complex problems, but limited application on open gobs should not be difficult, particularly where application can be made by mechanical blowers.

TREATMENT OF ENTRIES.

The previous tests have shown that a given percentage of incombustible material in a dust mixture will prevent the propagation of an explosion regardless of the amount of dust present. The quantity of rock dust needed in a given entry will depend directly upon the quantity of coal dust which is already present and which may be

deposited in the immediate future. The success of any rock-dust treatment will therefore depend upon the previous removal and further prevention, so far as possible, of coal-dust accumulations. It has been suggested that whitewashing helps to retard spalling and chipping, and "guniting" is an admirable method, retarding weathering.

KIND OF ROCK DUST TO USE.

DANGER TO HEALTH.

Objection has been made to the use of rock dust in this manner because of the alleged danger to miners' lungs. Dust containing free silica or hard particles of any sort, which have sharp knifelike edges or needle points, if inhaled, might bring about a fibroid condition of the lungs. Such particles, however, may be detected easily by microscopic examination. Pulverized shale dust has been shown to be noninjurious by British commissions which have investigated this particular point.⁴⁶

It has been thought by some that ordinary mine ventilating currents would raise the rock dust into the air to such an extent that it would be disagreeable, if not actually injurious, to the men. The British committee investigating this point found that very fine coal dust could be raised into the air with the velocity of 1,200 feet per minute,⁴⁷ whereas the coarser coal-dust particles ordinarily deposited from the air current would be picked up again by velocities of 1,600 feet per minute. On the other hand, velocities of 2,600 feet per minute would be required to move the shale dust. In this connection it might be mentioned that the velocity of very slow explosions is always greater than 3,000 feet per minute.

STICKING QUALITIES.

Another factor to be considered in determining the size of rock dust to be used is the ability to make the dust stick to the mine surfaces. The finer the dust the better it will stay on the ribs and roof. The limestone dust which is being used in the mines around Pittsburgh, Pa., averages 97.5 per cent through 20-mesh and 47 per cent through 200-mesh. Where the dust is thrown on by hand, as it is in these mines, there is no difficulty in making a very heavy coating stick to the smooth coal surfaces. It is quite probable that dust with a smaller percentage of the 200-mesh particles would be just as satisfactory if plenty were present.

Where the dust is to be blown into the air by a machine and allowed to drift with the ventilating current for some distance the finer the dust the better it will work. The British recommend for this purpose dust all of which will pass through 50-mesh and 70 per

⁴⁶ Colliery Guardian, Seventh Report, Explosions in Mines Committees (British). Effects of inhaling dusts applicable for stone dusting in mines: Vol. 110, December 10, 1915, pp. 874-875.

⁴⁷ Iron and Coal Trades Review: Vol. 94, February 7, 1917, p. 127.

cent of which will pass through 180-mesh. However, in the Delagua mines of Colorado, where a blower is used, the largest adobe dust particles are about one-eighth inch in size, with 20 to 30 per cent passing through 200-mesh. These mines, however, have shelves along the ribs which catch the coarser particles while the finer particles float through the air, settling upon all surfaces.

As the cost of preparing the dust increases with the fineness, it is desirable to use the coarsest dust that will operate satisfactorily for the particular method used, provided that at least 95 per cent will pass through 20-mesh and 25 to 30 per cent through 200-mesh, as indicated previously by the tests at the experimental mine. Crushing machines may be obtained which will take pieces 2 to 3 inches in size, and reduce them to the proper 20-mesh size with one operation. When dust with a much greater percentage of 200-mesh particles is desired, it is generally necessary to use two machines, first crushing the dust to about one-sixteenth or one-eighth inch and then pulverizing it in a second machine.

AFFINITY FOR WATER.

As described on page 407, the presence of large percentages of shale assists in any wetting methods which may be employed for neutralizing the coal dust. There is probably not enough difference in the affinity for water, however, between the various materials available for rock dusting to make this feature important in the consideration of some particular material.

On the other hand, where a strictly dry method is to be used it should be kept in mind that a shale or rock-dust coating on the entry surfaces will not stop an explosion when the dust becomes too wet to be raised into the air in a cloud. For this purpose, then, it is preferable to have a dust which will not take up moisture readily.

REMOVAL OF COAL DUST.

It is obvious that less rock dust will be required to maintain a given percentage of incombustible material in a given section if the coal-dust accumulations in that section are previously removed. The accumulations of very fine dust along the ledges of ribs and on timbers as well as the larger pieces on the floor, may be blown away by compressed-air jets. This method of cleaning, which is not always adaptable, will of course produce a dense cloud of coal dust, which will be carried along in the air current for a considerable distance. For this reason such work should be done when most of the workers are out of the mine. The direction of the air current should also be so arranged that the coal-dust cloud will be carried outside of the mine if possible, or at least not into some section which has already been treated with rock dust. Extreme care should be observed to prevent ignition of this dust cloud by open lights or accidental sparks.

An ordinary house vacuum cleaner was tried in the experimental mine for removing dust, but the irregular surfaces of the walls and floor made it ineffective; a more powerful vacuum cleaner might be successful. In Great Britain a vacuum cleaner combined with blowing side jets has been manufactured and is said to be effective.

MECHANICAL METHODS OF ROCK DUSTING.

In Delagua mine, Colorado,^{47a} adobe dust is applied, for the purpose of preventing explosions, by means of an air blast produced by an electrically driven blower mounted on a mine truck, which also carries a bin containing adobe dust. The dust is ejected through a flexible hose pipe by the air blast. A dense cloud of dust can be directed to the walls of the passageway and the timbering, coal dust that has found lodgment being blown away and supplanted by adobe dust. This has proved a cheap and effective way to dislodge coal dust and to fill the crevices with inert dust. Moreover, the finest inert dust floats along with the air current and finds lodgment beyond. As the adobe dust or rock dust has a steeper angle of repose than coal dust, any of the coal dust subsequently produced by the haulage of cars of coal along the entry way tends to roll off the rock dust onto the floor; when the mixture on the floor becomes too rich in coal dust it can be shoveled up and taken out of the mine.

An objection to this particular dust-blowing device was that the fan motor was electrically driven from a trolley wire, and the method of treatment was confined to trolley roads. With the advent of storage-battery locomotives, however, particularly those of explosion-proof type, the treatment can be carried into all parts of the mine where there is a track. A further advantage in the use of an air hose for ejecting the rock dust is that the hose can be inserted into a pipe connection or an opening with suitable valve in a cut-through stopping so that an extension hose can be taken through, thus providing dust treatment of a parallel entry or working place that has no track.

The dust cloud made by this machine, and a similar one tried at the experimental mine, is carried along in the air current for hundreds of feet. Consequently dusting is done when the mine is not in operation. Dusting starts at the return end of any passageway, the dust being blown in the direction of the air current, the machine then proceeding backward against the movement of the air current so that it and the attendants are working in air free from the ejected dust. Where electricity is not available, provision could be made to have the blower fan driven by gear or belt from the car wheels of the truck, so that the machine would operate when hauled by mules or rope.

^{47a} Duck, G. F., The Delagua, Colorado, explosion: *Mines and Minerals*, vol. 31, Jan., 1911, p. 374. An adobe dusting apparatus was designed and installed by Wm. J. Murray and Samuel Dean after the explosion disaster. See, also, General specifications for rock dusting machinery, *Coal Age*, vol. 9, Apr. 15, 1916, p. 672. Describes Bureau of Mines crushing machinery and mine-truck mechanical duster.

The extemporized rock-dusting machine with gasoline engine driving the fan, tried at the experimental mine, is shown in Plate XXXII. The use of a gasoline engine would not be safe for regular mine use because of the exhaust and danger of ignition of fire damp.

METHOD OF APPLYING ROCK DUST.

The more general method of applying rock dust to entries in this country is that of throwing by hand. Although at first thought this method appears to be slow, the cost is not excessive. In one mine near Pittsburgh, Pa., one man covered the roof and ribs of an entry with a thick coating of limestone dust, throwing a handful at a time with such force as to make the most of it stick to the surfaces. The rock dust was used at the rate of 7.5 pounds per linear foot of entry (7 feet by 9 feet in cross section), about 20 linear feet being covered per hour. The cost was about \$2.75 per hundred feet of entry treated.

TESTS OF MIXTURES OF PITTSBURGH COAL DUST, PIT-SHALE DUST, AND WATER.

It has been frequently urged that water was more effective in preventing coal-dust explosions than rock dust, because a much smaller weight of water than rock dust is necessary to make the same amount of coal dust inert. This is manifestly not the only consideration, but it was believed important to obtain information about the quantities of water necessary to make different sizes of coal inert in order to confirm or modify conclusions based on gallery tests made at the Pittsburgh experiment station in 1909.⁴⁸

Accordingly a series of tests, in which water was mixed with the coal, was made with four standard sizes of Pittsburgh coal dust. Various percentages of water were used, shale being added in each instance until the limiting mixture was obtained. All tests in this series were "standard propagation tests," no "ignition tests" being made, because even in carefully watered mines there might be enough dry coal dust, more or less pure, in a room or an entry to start an explosion. Pit shale was used in preparing the mixed dusts. All the tests were made without gas in the ventilating current. They may be divided into four classes:

- (1) Tests with pulverized Pittsburgh coal dust.
- (2) Tests with 20-mesh (40 per cent 200-mesh) Pittsburgh coal dust.
- (3) Tests with 20-mesh (20 per cent 200-mesh) Pittsburgh coal dust.
- (4) Tests with 20-mesh (10 per cent 200-mesh) Pittsburgh coal dust.

The results of these tests are presented in Table 45.

⁴⁸ Rice, G. S., and others, The explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, p. 56.

DISCUSSION OF TESTS.

TESTS WITH PULVERIZED COAL DUST.

Eight tests were made with pulverized coal dust—two with 10 per cent water, three with about 20 per cent water, two with 25 per cent water, and one with 30 per cent water in the mixture.

A mixture of 10 per cent water, 40 per cent shale dust, and 50 per cent coal dust gave strong propagation in test 334, pressures of 30 pounds and 48 pounds being recorded at stations E 950 and A 950, respectively. In test 335 a mixture of 10 per cent water, 60 per cent shale dust, and 30 per cent coal dust failed to propagate. The flame, however, extended 150 feet in the entry and 300 feet in the air course. Judging from the length of flame in this test and the high pressures obtained in test 334, a mixture of 10 per cent water, 50 per cent shale dust, and 40 per cent coal dust would give propagation.

In test 332 a mixture of 18 per cent water and 82 per cent coal dust gave very strong propagation. In test 373 a mixture of 20 per cent water, 30 per cent shale dust, and 50 per cent coal dust gave propagation. In test 375 a mixture of 20 per cent water, 40 per cent shale dust, and 40 per cent coal dust failed to propagate; the flame penetrated 75 feet only in the entry and 125 feet in the air course in the respective dust-treated zones.

Tests 333 and 371 were made with a mixture of 25 per cent water and 75 per cent coal dust and both gave strong propagation. In test 433 a mixture of 30 per cent water and 70 per cent coal dust failed to propagate, the flame extending 100 feet in the entry and 200 feet in the air course. The high percentages of water needed to prevent propagation fully confirm the results of the Pittsburgh gallery tests ^{48a}. With 25 per cent of water pulverized dust feels wet and with 30 per cent it is a black mud.

TESTS WITH 20-MESH (40 PER CENT 200-MESH) COAL DUST.

Three tests were made with 20-mesh coal dust, of which 40 per cent would pass through a 200-mesh screen, two with 10 per cent water, and one with 20 per cent water in the mixture. In test 342 a mixture of 10 per cent water, 40 per cent shale dust, and 50 per cent coal dust gave propagation. In test 343 a mixture of 10 per cent water, 50 per cent shale dust, and 40 per cent coal dust gave weak propagation. The velocities and pressures in this test were very low.

From these results it is reasonably certain that a mixture of 10 per cent water, 60 per cent shale dust, and 30 per cent coal dust would prevent propagation, as would probably a mixture of 15 per cent water, 45 per cent shale dust, and 40 per cent coal dust. In test 341 a mixture of 20 per cent water and 80 per cent coal dust failed to propagate.

^{48a} Rice, G. S., and others, Work cited, pages 56-58.

TABLE 45.—*Results of standard propagation tests of mixtures of Pittsburgh coal dust, pit-shale dust, and water.*

[Originating cause: Standard blown-out shot from cannon at station E 1300. Ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, a distance of 50 feet.]

MIXTURES OF WATER WITH PULVERIZED COAL DUST AND PULVERIZED SHALE DUST.

Test No.	Date.	Proportions of mixture.		Mixed dust			Records obtained in entry or in air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Remarks.			
		Water.	Shale.	Coal.	Total moisture.	Calculated moisture.		Rate of load-ing.	Total load-ing.	Station 1150.	Station 950.	Fall at station 1250.	Ve-locity.	Fall at station 1150.	Ve-locity.			Fall at station 1050.	Ve-locity.	Fall at station 950.
334	1916. Oct. 16...	10	40	50	Per cent. 10.6	Per cent. 82.8	Lbs. per ft. 2.00	Lbs. 1,300	{Entry..... {Air course.	Lbs. per sq. in. 28 30	Sec. und. 0.460	Sec. und. 0.662	Sec. und. 0.908	Sec. und. 1.613	Sec. und. 1.758	Sec. und. 0.870	Sec. und. 0.913	{ (a) } { (a) }	{ Propagation ob- tained.	
335	Oct. 18...	10	60	30	11.6	71.9	3.33	2,167	{Entry..... {Air course.	2 2	.573	81	2.532	31	5.798	115	2.342	150 300	{ Propagation not obtained.	
332	Oct. 9...	18	0	82	19.3	24.0	2.00	1,300	{Entry..... {Air course.	35 47	.....	.....	.925	1,471	.893	3.704	.920	{ (a) } { (a) }	{ Propagation ob- tained. In this test ignition was at station A 1300, the ignition zone A being stations A 1300 to A 1250.	
373	1917. Jan. 19...	20	30	50	20.0	53.2	2.00	1,300	{Entry..... {Air course.	8 9	.613	243	1.025	763	1.278	380	1.552	{ (a) } { (a) }	{ Propagation ob- tained.	
375	Jan. 24...	20	40	40	19.1	62.5	2.50	1,625	{Entry..... {Air course.	1 1	.297	26	4.114	.....	.....	.....	.....	75 125	{ Propagation not obtained.	
333	1916. Oct. 11...	25	0	75	27.4	80.9	2.00	1,300	{Entry..... {Air course.	42 34	.529	293	.892	535	1.049	534	1.076	{ (a) } { (a) }	{ Propagation ob- tained. Moisture in samples varied from 23.2 to 42.5 per cent.	
371	1917. Jan. 16...	25	0	75	24.2	31.7	1.33	947	{Entry..... {Air course.	30 33	293	248	.887	505	.895	3.704	.912	{ (a) } { (a) }	{ Propagation ob- tained.	
433	May 25...	30	0	70	31.0	35.6	2.67	1,733	{Entry..... {Air course.	1 2	.262	41	2.716	.....	.....	.....	.....	100 200	{ Propagation not obtained.	

MIXTURES OF WATER WITH 20-MESH SHALE DUST AND 20-MESH COAL DUST, OF WHICH 40 PER CENT WOULD PASS 200-MESH.

1916.	10	40	50	11.2	58.4	2.00	1,300	{Entry Aircourse.	13	11	0.377	175	0.947	224	1.393	1,010	1.492	{(e)	{Propagation ob- tained.
342 Nov. 6...									12	12			1.168	1,399	1.235	1,042	1.331		
343 Nov. 8...	10	50	40	11.2	68.2	2.50	1,625	{Entry Aircourse.	2	2	.367	117	1.321	87	2.368	95	3.422	{(e)	D.O.
									2	2			1.387	148	2.084	113	2.948		
341 Nov. 3...	20	0	80	21.5	28.4	2.50	1,625	{Entry Aircourse.	2	2	.666	61	2.295					175	{Propagation not obtained.
									2	2			1.930				200		

MIXTURES OF WATER WITH 20-MESH SHALE DUST AND 20-MESH COAL DUST, OF WHICH 20 PER CENT WOULD PASS 200-MESH.

	1916.	10	30	60	12.0	44.9	3.33	2,167	{Entry..... {Aircourse.	4	3	0.440	52	2.381	.....	378	2.893	{Propagation ob- {tained.	
336	Oct. 24....									2	2			1.515	158	2.146	2.326	(c)	
339	Oct. 30....	15	0	85	16.2	20.8	2.36	1,529	{Entry..... {Aircourse.	7	8	.421	78	1.599	472	1.911	901	2.022	Do.
340	Nov. 1....	15	10	75	15.6	30.3	2.67	1,733	{Entry..... {Aircourse.	1	2	.422	51	2.400	.....	.....	1.066	(c)	
337	Oct. 26....	20	20	60	21.1	44.6	3.33	2,167	{Entry..... {Aircourse.	1	1	.422	.....	2.048	.....	.....	.....	125 200	Propagation not obtained.
338	Oct. 27....	20	0	80	21.6	25.8	2.50	1,625	{Entry..... {Aircourse.	2	1	.792	46	2.878	.....	.....	.....	50 75	Do.
										1	1		.....	1.897	1	.....	.....	75 150	Do.

MIXTURES OF WATER WITH 20-MESH SHALE DUST AND 20-MESH COAL DUST, OF WHICH 10 PER CENT WOULD PASS 200-MESH.

1917.	5	35	60	5.8	44.2	3.50	2,275	{Entry..... {Aircourse.....	3	5	0.420	116	1,282	183	1,828	318	2,142	{(a) }	{Propagation ob- tained.
432 Apr. 24...	5	35	60	5.8	44.2	3.50	2,275	{Entry..... {Aircourse.....	3	5	0.420	116	1,282	183	1,828	318	2,142	{(a) }	{Propagation ob- tained.
374 Jan. 22...	5	45	50	7.4	54.0	2.00	1,300	{Entry..... {Aircourse.....	2	1	.417	129	1,193	40	3,724	150	225	{150 225}	{Propagation not obtained.
431 Apr. 23...	10	6	90	11.1	16.3	2.22	1,444	{Entry..... {Aircourse.....	1	1	.367	52	2,310	124	3,119	120	3,474	{275 (a)}	{Propagation ob- tained in air course, but not in entry.
399 Jan. 11...	15	0	85	16.6	20.9	1.18	765	{Entry..... {Aircourse.....	1	1	.271	104	1,237	424	2,643	150	250	{150 250}	{Propagation not obtained.

Flame extended through zones.

TESTS WITH 20-MESH (20 PER CENT 200-MESH) COAL DUST.

Five tests were made of 20-mesh coal dust, of which 20 per cent would pass through a 200-mesh screen, one being with 10 per cent water, two with 15 per cent water, and two with 20 per cent water in the mixture.

In test 336 a mixture of 10 per cent water, 30 per cent shale dust, and 60 per cent coal dust gave a weak explosion; therefore a mixture of 10 per cent water, 40 per cent shale dust, and 50 per cent coal dust probably would not propagate. In test 339 a mixture of 15 per cent water and 85 per cent coal dust gave moderately strong propagation. In test 340 a mixture of 15 per cent water, 10 per cent shale dust, and 75 per cent coal dust did not propagate. This test, however, is not far from the limit as the flame extended 200 feet in the air course. In test 337 a mixture of 20 per cent water, 20 per cent shale dust, and 60 per cent coal dust did not propagate. The flame penetrated only 75 feet into the zone thus loaded. In test 338 a mixture of 20 per cent water and 80 per cent coal dust failed to propagate. The flame extended 75 feet from the ignition zone in the entry and 150 feet in the air course into the respective dust-treated zones.

TESTS WITH 20-MESH (10 PER CENT 200-MESH) COAL DUST.

Four tests were made with 20-mesh coal dust, of which 10 per cent would pass through a 200-mesh screen. Two of the tests were with 5 per cent water, one with 10 per cent water, and one with 15 per cent water in the mixture. In test 432 a mixture of 5 per cent water, 35 per cent shale dust, and 60 per cent coal dust gave propagation. In test 374 a mixture of 5 per cent water, 45 per cent shale dust, and 50 per cent coal dust failed to propagate. In test 431 a mixture of 10 per cent water and 90 per cent coal dust gave incomplete propagation. The flame stopped at the point E 975. Judging from this and the decreasing flame velocity in the air course, an explosion would not propagate through a long zone of this mixture. In test 369 a mixture of 15 per cent water and 85 per cent coal dust failed to propagate, the flame extending from the ignition zone 150 feet in the entry and 250 feet in the air course into the respective mixed dust zones.

SUMMARY OF RESULTS AND CONCLUSIONS.

The results of these tests (given in Table 45) are shown graphically in figure 48. These curves, there being one for each size of dust, show the relation between the percentage of moisture in the mixed dust and the total percentage of incombustible in the mixed dust, the latter including all added water and shale together with the moisture and ash of the coal.

These curves are interpreted in a manner similar to the explosibility curves of figure 45. Any mixture which when plotted falls above the curve is not explosive. Any mixture falling below the curve is explosive. Thus a mixture of 20-mesh (40 per cent 200-mesh) coal dust containing 15 per cent moisture and 60 per cent total incombustible is nonexplosive, because it falls above the curve for this size of coal dust. On the other hand, a mixture of 20-mesh

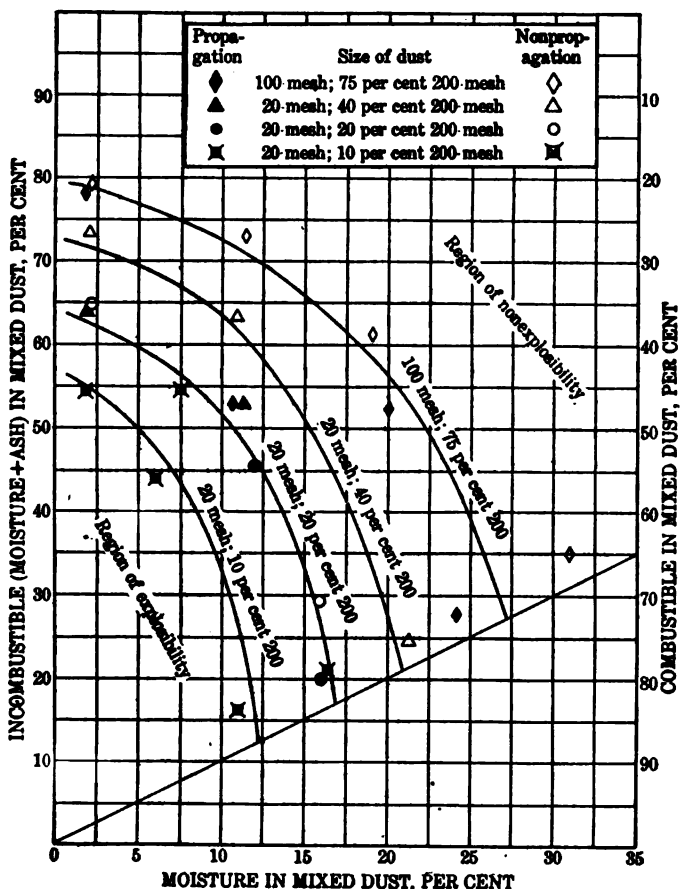


FIGURE 48.—Curves showing effect of free moisture on the explosibility of Pittsburgh coal dust, with and without shale dust.

(40 per cent 200-mesh) coal dust containing 15 per cent moisture and 40 per cent total incombustible is explosive, as it falls below the curve for this size of dust. Also, a mixture of 20-mesh (10 per cent 200-mesh) coal dust containing 10 per cent water and 25 per cent total incombustible would be explosive.

The following table, compiled from the figure, gives the percentages of incombustible necessary to prevent propagation for various

moisture contents of mixtures of Pittsburgh coal dust with shale dust. Dusts of other coal beds require the same amount or less of incombustible matter according to the ratios indicated by figure 45.

Proportions of incombustible necessary for preventing propagation with various moisture contents of mixtures of Pittsburgh coal dust and shale dust.

Percentage of moisture. ^a	Percentage of incombustible needed to prevent propagation in tests of—			
	Pulverized coal dust.	20-mesh coal dust.		
		40 per cent 200-mesh.	20 per cent 200-mesh.	10 per cent 200-mesh.
0	77	71	64	58
5	77	69	59	50
10	73	63	52	33
15	66	51	33	..
20	57	27	..	..
25	40	..	..	..
30	..	..	..	..

^a Not including moisture of composition of coal.

The following table gives the same results expressed in a different form, the percentage of shale in the mixture being given instead of the total percentage of incombustible. In considering this table it should be borne in mind that the ash and moisture content of the coal of the experimental mine averages 9 per cent:

Proportions of shale needed to prevent propagation with various moisture contents.

Percentage moisture. ^a	Percentage of shale needed to prevent propagation in tests with—			
	Pulverized coal dust.	20-mesh coal dust.		
		40 per cent 200-mesh.	20 per cent 200-mesh.	10 per cent 200-mesh.
0	76	69	61	54
5	69	62	50	41
10	60	50	38	18
15	47	32	13	0
20	33	2	0	.....
25	9	0	.....	.....
30	0	.....	.....	.....

^a Not including moisture of composition of coal.

These tables and curves indicate that water is two and one-half to three times as effective, by weight, as shale dust in preventing the propagation of an explosion.

Several causes have been suggested for this, one being the fact that water has a higher specific heat and absorbs a large quantity of heat on turning into steam. Another is that the water completely coats the

finer particles with a thin film, which excludes the air and consequently prevents combustion until all the water is evaporated. Perhaps the most important factor is the tendency of wet particles to stick together, making it difficult for the advance air waves to raise the dust into a dense cloud.

It should also be carefully noted that although water is more effective than the same weight of shale dust much more attention is required to keep the coal dust evenly moist. As previously stated, all the dust must be kept saturated at all times. The mixtures of water and coal dust (without shale dust) which prevented propagation in the experimental mine were in all instances pasty, and on a mine road would be churned into mud. A mixture of 25 per cent water and 75 per cent pulverized coal dust, which on two occasions gave a violent explosion, could be molded by the hands into a compact ball like damp clay.

There was given in Bulletin 20 (p. 58) a description of the physical condition of coal dust used in a gallery test, the dust having 30 per cent moisture. The tests just mentioned herein indicate that this test is not an index of the presence of sufficient water to prevent propagation in the case of pure fine coal dust, which must literally appear as mud to be inert, however, it would still apply in the case of ordinary road dust.

The greatest difficulty in applying the watering system is to keep the dust wet all the time; the rapidity with which it dries in the winter months requires extraordinary care daily, and systematic watering by one of the approved methods must be done in all parts of a mine not naturally wet.

The conclusion is then, that in order to render the coal dust in a mine inert a smaller quantity of water, by weight, would be required than of rock dust, but the sum of the daily applications of water must be considered as against the monthly or even less frequent applications needed in rock dusting. Moreover, the watering method requires much more attention, and if watering is not properly maintained it may give a sense of fancied security when there is dust in a dangerous condition in some part of the mine. It is highly advisable when the watering method is followed in a mine which contains dangerous dust that the watering be supplemented by inclosed rock-dust barriers, as described in Chapter VIII.

TESTS ON THE EFFECT OF VARYING HUMIDITY OF AIR CURRENT.

During an interval between explosion tests in the winter of 1912-13 a series of experiments was made to determine the effect of changes in humidity of the air current on the moisture content of coal dust and on that of mixtures of coal dust and shale dust, followed by tests with saturated and supersaturated air currents.

The coal dust and the mixtures were distributed to a depth of about one-half inch on wooden shelves along the sides of the entry. In the first tests these zones were swept by air currents whose temperature and humidity varied with the weather conditions above ground and with the distance traversed by the air currents in the mine. Observations were taken of the temperature, humidity, barometric pressure, and volume of air current. Temperature and humidity measurements were recorded continuously by means of a hygrodeik, which was usually placed near the intake, where the greatest variation in temperature and humidity took place. In addition measurements were made by observers with a Bureau of Mines sling psychrometer every three hours at the place where the hygrodeik was situated, and at other points in the mine. The comparison of psychrometer and hygrodeik readings showed a fairly close agreement.

The velocity of the air current was read once a day at the same point in the mine by means of an anemometer. The measurement was made by moving the anemometer through the entry cross section for one minute and then applying the correction from the manufacturer's chart. Samples of the dust were taken practically every day and analyzed for moisture.

Table 46 shows the average moisture content, in grains per cubic foot, in the intake and return air, as determined from humidity, temperature, and barometric pressure measurements; the amount of water, in gallons, absorbed from or deposited in the mine by the ventilating current in 24 hours, and the moisture content of the dust samples taken almost daily. The zone from which these samples were taken was 150 feet in by the intake and so would be more likely to respond quickly to changes of conditions in the air current than if it were situated farther in the mine.

TABLE 46.—*Effects of varying humidity of the air current on percentage of moisture in exposed coal dust.*

Date.	Water in intake air.	Estimated water in return air.	Difference.	Water absorbed (+) or deposited (−) by air.	Moisture in coal dust.
	Grains per cubic foot.	Grains per cubic foot.	Grains per cubic foot.	Gallons per day.	Per cent.
1912.					
Oct. 3					2.10
Oct. 4	5.03	4.37	−0.66	−35.14	2.06
Oct. 5	4.06	4.37	+ .31	+ 64.37	2.52
Oct. 6	4.09	4.37	+ .28	+ 55.75	
Oct. 7	4.06	4.37	+ .28	+ 55.75	3.47
Oct. 8	3.22	4.37	+1.15	+233.05	2.21
Oct. 9	4.53	4.37	− .16	− 33.70	2.28
Oct. 10	5.74	4.37	−1.37	−801.63	3.47
Oct. 11	5.74	4.37	−1.37	−801.63	
Oct. 12	5.27	4.37	− .90	−188.30	3.37
Oct. 13	3.51	4.37	+ .86	+179.63	
Oct. 14	3.09	4.37	+1.28	+278.57	2.25
Oct. 15	2.60	4.37	+1.77	+397.84	2.25

The range in moisture content of the coal dust was small during the period of test, the highest moisture content observed being only 3.47 per cent and the lowest 2.25. This was only a little higher than the moisture content of the original sample, which was 2.10 per cent. With the exception of the sample for October 7 the variation in general follows the changes of the air-current action in absorbing or depositing moisture. The sample for October 12 shows a lower moisture content than would be expected, as the air current had been depositing moisture. If the periods of deposition had been longer, then the moisture content would probably have been greater and in subsequent periods of absorption the reduction of moisture content would have been greater. The average velocity of the air current during this series was kept as uniformly as possible at 150 feet per minute.

STEAM HUMIDIFYING TESTS.

In January and February the air current was humidified with exhaust steam from a 3-inch pipe installed in the intake along the rib. This pipe has three rows of $\frac{1}{4}$ -inch holes, spaced 45 degrees apart, for a length of 20 feet. The holes in each row were 9 inches apart and were staggered with relation to the holes of the other rows. The amount of steam furnished was controlled by varying the speed of the fan engine, the quantity of air being kept at nearly the same volume by regulating the size of the fan intake. An effort was made so to regulate the volumes of steam and air that the fogging of air would not extend outby station E 800 on the return entry (see fig. 1, p. 14). At times the mist line, or point where the mist disappeared, was not easy to determine precisely, as the mist sometimes disappeared gradually in the air current. By attempting to limit the zone to the point mentioned the effect of a saturated air current on zones of coal dust and mixed dust outby this point could be determined.

The period during which the air was of practically 100 per cent humidity extended from January 28 to February 15. Humidity readings were taken at various points in the mine and observations as to the limit of the mist line made every three hours.

Table 47 includes complete readings about every fourth day, the others being omitted for brevity. Readings are given for the outside air and the air at the intersection of the fan drift and the air course. This intersection is about 180 feet beyond where the exhaust steam was admitted. The average increase in temperature during this test period was 19° F., the range of difference being from 1 $\frac{1}{2}$ ° to 29° F. This increase was due almost wholly to the temperature of the steam which was exhausted into the air current immediately inby station G 150, where the air conduit entered the concrete lined drift slant in the coal bed.

TABLE 47.—Effects of saturated and supersaturated air on moisture content of exposed coal dust.

Date.	Time.	Average velocity of air current.	Temperature and relative humidity of air.										Moisture content of samples gathered from stations E 350 to E 450.																													
			Outside of mine.		Station G 150.		Gallery and air course.		Station A 350.		Station A 1200.			End of line for line from steam jet.																												
			Temperature (°F.).	Humid-ity.	Temperature (°F.).	Humid-ity.	Temperature (°F.).	Humid-ity.	Temperature (°F.).	Humid-ity.	Temperature (°F.).	Humid-ity.																														
1913. Jan. 28	(9 a. m.	170	{ 29 34 33½ 33 31½ 31½	{ 78 81 85 90 100 100	{ 73 35	{ 47 100	{ 42½ 48 46 47½ 47½ 47½	{ 98 100 100 100 100 100	{ 47 47½ 48 48 48½ 48½	{ 100 100 100 100 100 100	{ 49 49 100 49½ 49½ 49½	{ 100 E 475 E 600 E 1250 E 475 E 475 E 550																														
	(3 a. m.												{ 130	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																				
	(6 a. m.																						{ 118	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800										
	(9 a. m.																																{ 103	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800
	(4 p. m.																																									
(12 m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
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(6 a. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(9 a. m.																					{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800												
(1 p. m.																															{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800		
(4 p. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
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(12 m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
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(6 a. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
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(1 p. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(4 p. m.											{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																						
(9 p. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(12 m.											{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																						
(3 a. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(6 a. m.											{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																						
(9 a. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(1 p. m.											{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																						
(4 p. m.	{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																																
(9 p. m.											{ 127	{ 101 4 73 13 12 6 7½ 5½	{ 95 100 81 60 60 76 71	{ 59 32 34 64 25½ 33 71	{ 53 34	{ 54½	{ 53 55 51½ 51½ 50½ 51	{ 76 100 100 100 100 100 100	{ 50 50 50 50 50 51 51	{ 100 E 475 E 600 E 1200 E 800 E 1100 E 600 E 600 E 800																						
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It will be observed that, although the mine is shallow, the return-air temperature after the first four days was practically constant at 51° F., although the outside air ranged from 4° F. to 45° F., and at the first station in by the steam jets the temperature ranged from 47° F. to 57° F.

The coal dust used in this test was pulverized dust which was distributed on the side shelves from E 350 to E 450 about December 15. During the latter part of January, 1913, the zone had been swept by an air current which for the greater part of the time was supersaturated; consequently considerable moisture had been deposited upon the dust. A sample taken January 28 showed 5.38 per cent moisture. The percentages of moisture in the coal dust on the other days of the test period are given in the last column of Table 47.

It will be seen that notwithstanding the fact that the mist line sometimes advanced to and beyond the coal-dust zone, so that some deposition of water took place, the amount was surprisingly small and the increase temporary. For the whole period the moisture content decreased from 5.38 to 3.03 per cent. The conclusion from this test would be that a saturated air current will not materially increase the moisture content of finely ground coal dust which is exposed to it; therefore reliance should not be placed on a saturated air current for wetting road and rib dust beyond the point where there is mist in the current. The effect is merely to retain whatever condition of moisture previously existed; if the dust is wet, then a saturated air current will not dry the dust. If a mine makes water or the dust is wetted by sprays or hose, the dust will probably remain wet, as no moisture will be removed by the air current. If the mine is naturally dry, the humidifying of the air with exhaust steam to a point of saturation should be supplemented by watering or some other method of rendering coal dust inert in the entries swept by return air currents.

TESTS IN WHICH CALCIUM CHLORIDE WAS USED FOR WETTING THE DUST.

In addition to the pure coal-dust zone, several other zones were installed in the same part of the mine during this period. The mixtures in these zones were as follows:

(1) Coal-dust deposit one-fourth inch in depth upon which a solution of calcium chloride (1 pound of CaCl_2 to 12 pounds of water) was sprinkled.

(2) A similar deposit upon which dry powdered calcium chloride had been sprinkled at the rate of one-fourth pound per foot of entry, or over an area of $1\frac{1}{4}$ square feet.

(3) A deposit of a mixture of 30 pounds of coal dust and 3½ pounds of dry calcium chloride.

(4) A deposit of 75 per cent coal dust and 25 per cent shale dust.

The drops of calcium chloride solution on top of the dust increased very rapidly until the drops combined and formed little pools on the dust. Oftentimes these pools increased to such size as to overflow the edge of the dust deposit, making such channels as can be seen in Plate XIV, A.

Table 48 gives the determinations of moisture in the samples taken daily during the test period. The later samples were collected by blowing the pools or drops of water off the dust and then sampling. It is probable that the higher moisture content in the early days of the test over those taken later is due to incomplete blowing off of water drops rather than differences in the actual moisture content of the dust. The samples taken on the 15th of February are interesting. Notwithstanding the large amount of water present on the surface of the deposits, as indicated by the moisture content of the full-section samples, after the water was blown off, the dust beneath is shown by the top samples to be very dry.

TABLE 48.—Results of determinations of moisture content of samples from dust zones treated with calcium chloride in various forms and shale dust.

Date.	Wet CaCl ₂ zone.	Dry CaCl ₂ zone.	Mixed CaCl ₂ zone.	Zone having mixture of 25 per cent shale dust and 75 per cent coal dust.
1913.				
Jan. 31	a 12.92	a 6.32	.....	a 2.35
Feb. 1	a 10.12	a 17.79	.....	a 3.31
Feb. 3	a 19.47	a 22.08	.....	a 3.51
Feb. 4	a 6.84	a 16.82	.....	a 3.39
Feb. 5	a 4.18	a 11.24	a 5.29	a 3.39
Feb. 6	a 8.67	a 23.65	a 20.84	a 3.20
Feb. 7	a 17.38	a 15.35	a 31.80	a 3.23
Feb. 8	a 8.18	a 15.01	a 30.96	a 3.51
Feb. 10	a 14.89	a 8.53	a 8.05	a 3.14
Feb. 11	a 10.97	a 9.08	a 35.49	a 3.19
Feb. 12	a 4.96	a 10.23	a 35.00	a 3.70
Feb. 13	b 2.81	b 8.01	a 35.08	a 3.60
Feb. 14	b 2.75	b 2.70	a 19.03	a 3.48
Feb. 14	c 2.65	c 2.58	.....	.....
Feb. 15	b 2.73	b 2.53	.....	a 3.48
	b 2.70	b 2.73	.....	a 3.38
	b 2.63	b 3.00	.....	a 3.43
	b 2.58	b 2.73	.....	a 3.33
	a 23.18	a 23.40	a 17.80	.....
	a 31.38	a 25.05	a 18.23	.....
	a 33.35	a 24.25	a 19.55	.....

a Samples are those which include dust from the full depth of dust deposit. The samples from the calcium-chloride zones were taken by scraping the water from the top of the dust deposit and sampling through the section.

b Samples were taken from top of one-eighth inch of dust after water was scraped off the top.

c Samples were taken from the lower one-eighth inch of the deposit.

d Samples were taken by the rejecting of all bubbles of water which could be shaken out of the dust deposit.



A. SOLUTION OF CALCIUM CHLORIDE SPRINKLED ON COAL DUST.



B. DRY CALCIUM CHLORIDE SPRINKLED ON COAL DUST.

The samples from the dry calcium chloride zone also show similar results. Plate XIV, *B*, shows the appearance of the deposit after the dry calcium chloride had collected pools of water, which it did within 24 hours. The samples taken on the last day of the test show the same relation as those from the wet calcium chloride zone.

As the dust beneath the pools of water in these zones did not become wet, a zone of mixed coal dust and dry calcium chloride was prepared. The analyses again show rapid collection of water. However, a considerable part of the moisture did not become attached to the dust, and analyses of dust taken after shaking drops of water from the deposit show that only about half of the moisture remained.

These tests show that calcium chloride applied either in dry form or in solution is very effective in collecting moisture, particularly from a saturated air current. However, in order that the moisture thus collected be of service in wetting the dust the two must be agitated and mixed quite thoroughly. In operating mines in which calcium chloride is used to wet the road dust the mixing action is obtained by the travel of men, mules, and haulage appliances.

The zone of 25 per cent shale dust and 75 per cent coal dust showed an increase of about 1 per cent moisture in the first day or two, but not much change afterwards. The result indicates that this percentage of shale when thoroughly mixed with coal dust would not assist much in increasing the moisture content of the mixture over that of the pure coal dust. This might not be the case if the shale dust was in bunches as found under ordinary mine conditions. It has also been demonstrated by laboratory tests that larger percentages of shale naturally assist in the absorption of water by the mixture.

EFFECT OF SHALE DUST IN ASSISTING THE MOISTENING OF COAL DUST.

At a later date, when mixtures of dust having 60 or more per cent shale were distributed in the mine in preparing explosion tests, it was found that portions which fell upon damp places in the floor rapidly became wetted. On this account a series of tests was made on different mixtures of shale and coal dust to determine their relative speed of absorption of moisture. Blotters containing the different mixtures were placed on the surface of water in basins and observations made as to the relative speed of the wetting of the different mixtures. It was found that a mixture of 80 per cent shale dust and 20 per cent coal dust would absorb moisture almost as rapidly as pure shale dust; a mixture having 60 per cent shale dust, more slowly than shale dust; and a mixture containing less than 50 per cent shale dust became wetted not much more rapidly than pure coal dust.

The following series of tests to determine the same relation was made in the laboratory under the direction of A. C. Fieldner, chemist in charge:

LABORATORY TESTS ON THE ABSORPTION OF WATER BY COAL AND SHALE DUSTS AND MIXTURES THEREOF.

A series of experiments on coal dust, shale dust, and mixtures thereof was made in the laboratory at Pittsburgh under the direction of A. C. Fieldner to show the relative rate of absorption of water by these dusts. The apparatus used, shown in figure 49, consisted of

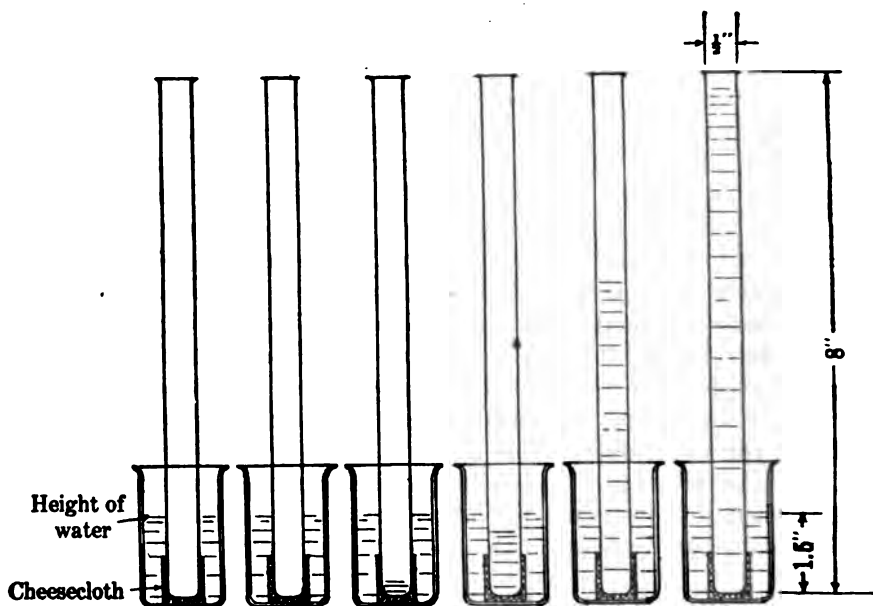


FIGURE 49.—Apparatus for measuring rates of absorption of water by coal dust and various coal and shale dust mixtures.

six $\frac{1}{2}$ -inch glass tubes 8 inches high, supported vertically, the bottom of each tube resting in a beaker of water. The height of water in the beaker was 1.5 inches, the bottom of the tube having four thicknesses of cheesecloth tied across it to prevent the dust falling out during handling. The six tubes contained six different mixtures of coal dust and shale dust as follows:

- (1) One hundred per cent coal dust.
- (2) Eighty per cent coal dust, 20 per cent shale dust.
- (3) Sixty per cent coal dust, 40 per cent shale dust.
- (4) Forty per cent coal dust, 60 per cent shale dust.
- (5) Twenty per cent coal dust, 80 per cent shale dust.
- (6) One hundred per cent shale dust.

For these tests Pittsburgh coal dust obtained from the experimental mine and pit-shale dust were used. The dust was ground to pass a

60-mesh screen and air dried before use. The mixtures were not packed tightly, being simply poured into the tubes. The six tubes were simultaneously placed in the beakers and the height of the water level in the tubes at different times was noted. The rise could easily be seen from the moist appearance of the mixture.

This first set of tests was not satisfactory, owing to the capillary action of the glass tubes on the water. The experiment was then repeated with the glass tubes coated with a thin layer of paraffin. Coating the tubes with paraffin overcame the difficulties encountered, and good results were obtained from the second set of tests. The height of the water level in the various tubes, however, could not be read with any degree of certainty through the paraffin coating; consequently the tubes were allowed to stand until the water appeared at the top of the pure shale dust, which took place at the end of 36 hours. The tubes were then inverted and gently tapped, the dry dust being permitted to flow out of the tube. The height of the wet portion remaining could then be easily measured. The height of the dust remaining in the various tubes was as follows:

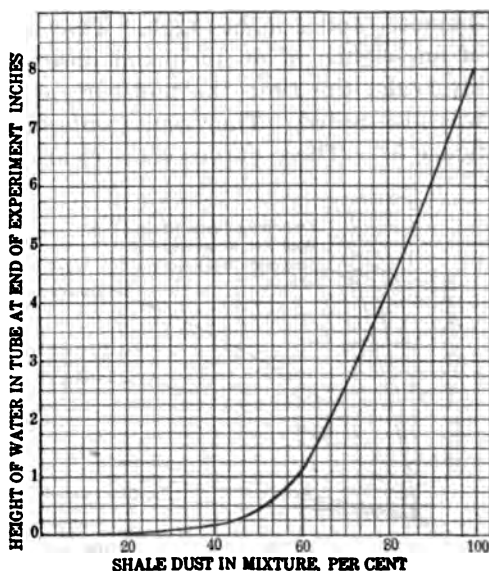


FIGURE 50.—Curve showing effects of increasing shale percentage on the absorption of water by mixtures of coal dust and shale dust.

Results of wetting tests.

Tube No.	Percentage mixture.	Height of wetted material (inches).
1	100 per cent coal dust.....	0.0
2	80 per cent coal dust, 20 per cent shale dust....	.0
3	60 per cent coal dust, 40 per cent shale dust....	.16
4	40 per cent coal dust, 60 per cent shale dust....	1.12
5	20 per cent coal dust, 80 per cent shale dust....	4.32
6	100 per cent shale dust.....	8.00

Figure 49 shows the height of the water in the various tubes at the end of the experiment. It will be observed that the pure coal dust was not wetted at all and that the mixtures containing 60 per cent shale or less were wetted very slowly. The pure shale dust

absorbed the water rapidly. In figure 50 the composition of the dust is plotted against the absorption of water in 36 hours. This curve shows distinctly the sudden change in the rate of absorption when the mixture contains 40 to 60 per cent shale dust.

After this experiment was completed a number of samples of road dust and rib dust were obtained from a mine working the Indiana No. 5 seam. These were tested in comparison with pure pit-shale dust and Pittsburgh coal dust from the experimental mine. The tubes used in this series of tests were three-fourths of an inch in diameter and 2 inches high. They were placed in water to a depth of one-eighth of an inch and observations were taken at frequent intervals; the time the moisture appeared at the top of the tube was also noted. The results obtained in these tests are plotted in figure 51. These curves show clearly the decreasing rate of absorp-

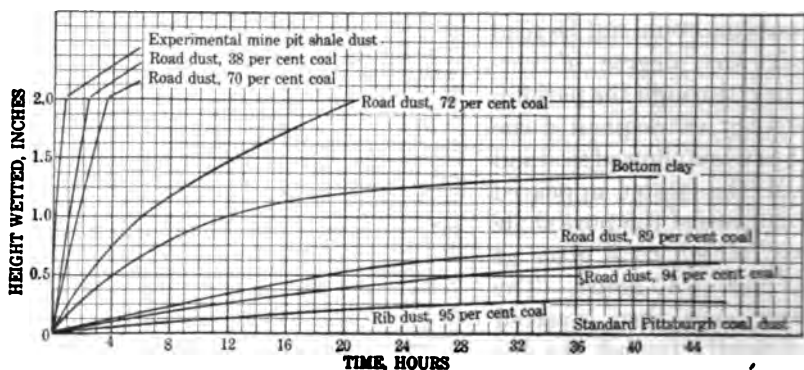


FIGURE 51.—Curve showing relative rates of absorption of water by road and rib dusts from a mine working the No. 5 seam, Indiana.

tion of water with the increasing per cent of coal dust in the sample: thus pure pit-shale dust was completely wet in one hour. A sample of road dust containing 38 per cent coal dust was completely wet in a little over two hours, whereas one containing 72 per cent coal dust was not completely wet at the end of 20 hours. Other samples of road and rib dust containing a larger percentage of coal dust were not completely wet when the experiment was stopped. A sample of bottom clay from the mine in Indiana was an exception to the rule. This clay could not be wetted as readily as some road dusts containing a much lower percentage of ash, and the water had not reached the top of the tube when the experiment was stopped.

It can therefore be readily seen from these experiments that a high percentage of shale dust will greatly assist in any wetting methods which may be employed for neutralizing coal-dust accumulations in a mine. The laboratory test fully confirmed the observations that had been made from time to time in the experimental mine.

TESTS ON THE RELATIVE RATE OF DRYING OF VARIOUS MIXTURES OF COAL DUST, SHALE DUST, AND WATER.

After it had been established that a mixture of coal dust with shale dust would absorb water more readily than pure coal dust the question naturally rose as to which would dry out the faster when swept by an unsaturated air current. It had been observed in the mine that when pure wet coal dust was dried by an air current the dust did not stick to the surface on which it was resting, but after it was thoroughly dry it could be raised in a cloud by a light puff of air. On the other hand, a mixture containing a large amount of shale dust packed together when wet seemed to dry out very slowly, and when dry stuck to the surface on which it was resting in a manner similar to dried mud. It was decided to obtain some definite evidence concerning the comparative rate of drying of pure coal dust, pure shale dust, and mixtures thereof.

Mixtures of the coal and shale dusts with water were exposed in an atmosphere having a known humidity. They were then weighed at intervals and the loss noted. The samples used averaged about 1 ounce each. These samples were necessarily small, because a considerable expenditure of time and

material would be necessary to produce an apparatus in which constant humidity could be maintained over a large sample of dust.

After some preliminary experiment to obtain a general idea of what might be expected, three samples of dust were prepared and a six-day test run thereon. These three samples had the following composition: (1) 80 per cent coal dust, 20 per cent water; (2) 40 per cent coal dust, 40 per cent shale dust, 20 per cent water; (3) 80 per cent shale dust, 20 per cent water. The temperature was maintained at 69° F. and the humidity was 79 per cent. The samples lost weight throughout the entire test, but more rapidly near the beginning. The mixture of pure coal dust and water lost about 13 per cent in weight in the six days. The mixture of coal dust, shale dust, and water lost slightly under 9 per cent, and the mixture of pure shale dust and water

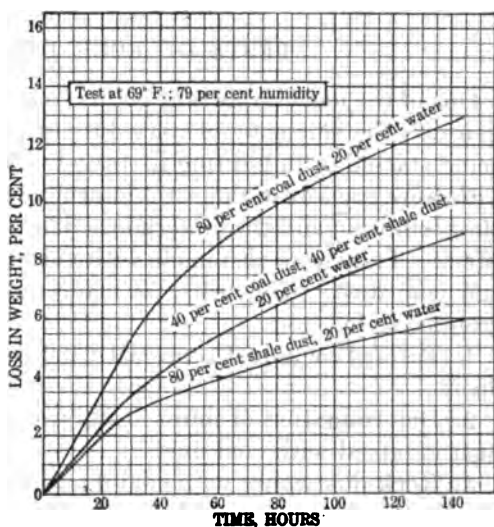


FIGURE 52.—Curves showing rates of evaporation of water from mixtures of pulverized Pittsburgh coal dust and pit shale dust.

lost about 6 per cent in weight. Figure 52 shows the relative rate of evaporation of water from the three samples.

These tests pointed to the conclusion that shale dust not only assists materially in wetting coal dust, but also helps to retain the water in the mixture when it is subjected to drying. There would probably be some difference in the actual rates of drying in large quantities of dust in a mine, and different sizes of dust particles would also give different results. Nevertheless, the qualitative fact is established that the pure coal dust will dry out more rapidly than the shale dust or a mixture of coal and shale dust. This places beyond doubt the value of shale dust in helping to wet coal dust where the wetting method of rendering the dust inert is used.

TESTS OF ROCK-DUST ZONES.

One of the most important points to be determined in the investigation was the efficiency of rock dust in preventing an explosion from being started or in limiting its travel. A number of tests were made with pure rock-dust zones to determine the efficiency of the method of distribution and the material used in obtaining the desired limiting effect. Tests were also made with various combinations of rock dust and coal dust. The tests, as made on rock-dusted zones, may be grouped as follows:

1. Tests of rock-dust zones with 300-foot ignition zones of pure coal dust.
2. Determination of limits (tests previously described) when shale dust is mixed with coal dust.
3. Rock-dust zones with coal-dust mantles.
4. Early tests on rock-dust zones—coal-dust zone with rock-dust mantle.
5. Tests showing comparative effect of coarse and fine sizes of shale dust.
6. Tests of rock-dust zones in the butt entries.

TESTS OF ROCK-DUST ZONES WITH 300-FOOT IGNITION ZONES.

Seven tests were made of rock-dust zones in which the rock dust was placed on side shelves to determine its efficiency in extinguishing explosions started in 300-foot coal-dust zones. Pure Pittsburgh coal dust was distributed on side shelves from the face of the entry to station E 1000, a distance of 300 feet, and also in the 1250 cut-through. The igniting shot was fired from a cannon at the face of the entry. The principal data on these tests are shown in Table 49.

TABLE 49.—Tests of rock-dust zones with 500-foot ignition zone.

[Originating cause: Standard blown-out shot from cannon at station E 1300. Ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1000, 300 feet; 1250 out-through, 50 feet. Rate of loading, 50 pounds per foot in entry and cut-through, 50 pounds on bench, total loading, 750 pounds.]

Test No.	Date.	Rock-dust zone.					Maximum pressure.					
		Zone. ^a	Total length.	Kind of dust.	Incombustible material.	Rate of loading.	Total loading.	Station E 1150.	Station E 980.	Station E 760.	Station E 540.	Station E 350.
			Feet.		Per cent.	Pounds per foot.	Pounds.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.
84b	1914, Feb. 9	Stations E 1600 to E 500.....	500	Rock shale.....	91.7	3	1,500	20	19	9	6	6
85	Feb. 12	do.....	500	do.....	91.9	3	1,500	.....	19	.....	7	.....
86	Feb. 13	do.....	500	do.....	91.6	3	1,500	.....	39	13	12	.....
87	Feb. 16	do.....	500	do.....	91.6	5	2,500	.....	30	9	7	6
88	Feb. 18	do.....	500	do.....	90.9	5	2,500	.....	32	8	10	12
90	Feb. 21	Stations E 1000 to E 400.....	600	Limestone.....	100.0	5	3,000	.....	30	16	7	6
91b	Feb. 24	do.....	600	do.....	100.0	5	3,000	.....	43	24	14	9

Test No.	Date.	Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in rock-dust zone.	Remarks.
		Fall at station E 1150.	Fall at station E 980.	Velocity.	Fall at station E 750.	Velocity.	Fall at station E 550.		
		Seconds.	Seconds.	Feet per second.	Seconds.	Feet per second.	Seconds.	Feet.	
84b	1914, Feb. 9	0.745	0.812	556	1.173	424	2.810	500	Flame did not extend beyond rock-dust zone.
85	Feb. 12	.731	1.141	.....	.....	.....	.....	700	Flame extended beyond rock-dust zone.
86	Feb. 13	.637	.715	.....	.....	.....	.....	500	Flame did not extend beyond rock-dust zone.
87	Feb. 16	.793	1.029	.....	.....	.....	.....	350	Do.
88	Feb. 18	.835	1.064	824	1.307	.....	.....	400	Do.
90	Feb. 21	.792	.....	1,156	1.138	346	1.715	700	Flame extended beyond rock-dust zone.
91b	Feb. 24	.644	.846	2,198	.937	772	1.198	700	Do.

^a Rock dust partly placed on side shelves and partly scattered on floor and ribs.

^b Flame velocity and pressure curves of tests 84 and 91 shown respectively in figures 57 and 58.

In tests 84, 85, and 86 roof shale was distributed from stations E 1000 to E 500 at the rate of 3 pounds per foot.^{ab} At station E 950 the maximum pressures in these tests were 19, 19, and 39 pounds, respectively, so that the explosion was fairly strong when it entered the rock-dust zone. In all instances the maximum pressures decreased as the explosion advanced; in two tests the last guncotton which was burned by the flame or the hot gases from the explosion was at station E 500, but in test 85 the last guncotton burned was at station E 300.

In tests 87 and 88 the rock dust was distributed at the rate of 5 pounds per foot on the side shelves^{ab}; the maximum pressures for these two tests at station E 950 were 30 and 32 pounds, respectively. In test 87 the pressures decreased as the explosion advanced, but in test 88 the pressures increased from E 750 to E 350. In both of these tests the flame was shorter than in the three previous tests when the shale-dust loading had been three pounds per foot, extending in test 87 only to E 650 and in test 88 to E 600, a distance of 350 and 400 feet into the rock-dust zone, respectively. The average analysis of the shale used in the five tests showed 8.5 per cent combustible. An even better showing might have been made with shale dust free from combustible matter. The slight increase in pressure in test 88, after the flame had been extinguished, is exceptional and unaccountable, but it is probably an instrumental error.

In tests 90 and 91 limestone dust was used in order to compare its effect with that of shale dust. The limestone was distributed at the rate of 5 pounds per foot on the side shelves just as the shale had been in tests 87 and 88. The flame extended 700 feet into the limestone zone in both tests, whereas for the same weight of loading in the shale tests the length of penetration was 350 and 400 feet, respectively. The comparison in favor of the shale dust is perhaps due to the greater specific gravity of the limestone dust. Although the flame penetrated through the limestone-dust zone, the pressure in the two tests was dropping so rapidly that the flame would have been extinguished in another 100 feet or so of dust zone.

It is believed that these explosions would have been stopped in a shorter distance if the dust had been scattered over the entire surface of the entry instead of being placed on the side shelves alone, and it would have been still more effective if placed on cross shelves.

The results of these tests show the value of a continuous rock-dusted entry in limiting an explosion, but also indicate that treatment by zones with untreated areas interspersed would not be a safe method, the penetration of flame being too great. As such zones in operating mines become contaminated by coal dust the efficiency for limiting an explosion would decrease, and as the percentage of com-

^{ab} Two pounds per foot on side shelves, remainder scattered.

bustible matter approached the amount that would permit propagation by the coal dust of that particular mine, additional rock-dusting would be necessary in all parts of the mine.

DETERMINATION OF LIMITS OF EXPLOSIBILITY WHEN SHALE DUST IS MIXED WITH COAL DUST.

The percentage of coal dust that may be present before the mixture of coal dust and rock dust becomes capable of propagating an explosion has been determined for a number of coals in the explosibility tests (see p. 94). However, in these tests the dusts were intimately mixed, whereas in operating mines the mixtures would not be so intimate, most of the coal dust, particularly that on ledges of the ribs, being on top of the rock dust.

The dust found in mines is generally coarser than that used in these tests. For this reason samples of road and rib dusts from various mines were examined to determine the proportions of the different sizes present; following this, standard methods of testing the explosibility of mine dusts were developed, as described in previous chapters.

ROCK-DUST ZONES WITH COAL-DUST MANTLE.

The question naturally arises, in using rock dust to prevent explosions, as to how long will it be effective under practical mine operations in which more or less fresh coal is being made and distributed by the ordinary mine agencies, such as haulage. To obtain information on this subject it was decided to run a series of tests to determine whether rock dust covered with a layer of coal dust became valueless as an explosion preventive.

DESCRIPTION AND RESULTS OF TESTS.

Tests 183 to 188 were made with 50-foot ignition zones of pure Pittsburgh coal dust, outby which rock dust was distributed at the rate of 5 pounds per foot, with various amounts of fine or coarse coal dust on top of the rock dust.

The rock dust used in these tests was pulverized pit shale and was thrown onto the surfaces by hand until they were completely coated. The coal dust was then either thrown into the air current from which it settled out on the rock dust or was thrown directly on the surfaces. Before the shot was fired six samples were gathered from the ribs and roof from strips 6 inches wide, and six samples were taken from the floor in the same cross section. The percentage of shale in these samples was determined and averaged for the particular test. Some of the samples showed a wide variation, but the average for all samples is thought to represent fairly accurately the ratios of coal and shale present. The essential data on these tests are shown in Table 50.

TABLE 50.—Standard propagation tests on rock-dust zones covered with coal-dust maniles.

[Originating cause: Standard blown-out shot from cannon at station E 1300. The ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1250, 50 feet. The shale and coal dust zone extended from stations E 1250 to E 960, 300 feet, and from stations E 1250 to A 950, 350 feet; total length, 650 feet.]

Test No.	Date.	Shale and coal dusts.						Incombustible.			
		Shale dust.		Coal dust.				In road dust.		In rib dust.	
		Attempted ratio of coal dust to shale dust.	Size.	Rate of loading.	Total loading.	Size.	Rate of loading.	Total loading.	Per ct.	Per ct.	Average.
183	1915. Mar. 1	20 : 80	Pulverized.....	Lbs. per ft. 5	Pounds. 3,250	Pulverized.....	Lbs. per ft. 1.25	Pounds. 812	45.1	Per ct. (a)	.....
185	Mar. 5	23 : 77	do.....	5	3,250	do.....	1.50	975	65.6	84.3	72.0
184	Mar. 3	25 : 75	do.....	5	3,250	do.....	1.67	1,083	63.6	81.2	70.1
188	Mar. 12	30 : 70	do.....	5	3,250	do.....	2.14	1,391	57.6	70.5	63.0
186	Mar. 8	25 : 75	do.....	5	3,250	20-mesh (34 per cent 200-mesh).....	1.67	1,083	62.7	75.9	67.1
187	Mar. 10	30 : 70	do.....	5	3,250	20-mesh (34 per cent 200-mesh).....	2.14	1,391	53.4	79.4	60.9

Test No.	Date.	Records obtained in entry or air course.	Maximum pressure.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed dust zone.	Propagation obtained.
			Station 1150.	Station 900.	Fall at station 1250.	Velocity.	Seconds.	Ft. per sec.	Fall at station 1050.	Velocity.	Seconds.	
183	1915. Mar. 1	{Entry..... {Air course.....	Lbs. per sq. in.	Lbs. per sq. in.	Seconds.	Ft. per sec.	Seconds.	Ft. per sec.	Seconds.	Ft. per sec.	Seconds.	125 123 } No.
			0	0	0	.....	2.753	.....	.....	.....	.....	
185	Mar. 5	{Entry..... {Air course.....	1	1	0.504	41	2.971	.....	.....	.....	.....	175 225 } No.
			2	0	.....	.....	.....	.....	.....	.....	.....	
184	Mar. 3	{Entry..... {Air course.....	2	2	.766	35	3.632	205	4.120	.....	.....	(b) Yes.
			2	.....	.....	.....	.....	.....	3.141	.....	4.327	
188	Mar. 12	{Entry..... {Air course.....	10	20	.434	177	1.000	.....	.....	429	1.466	(b) Yes.
			12	10	.....	.....	.948	592	1.157	672	1.306	
186	Mar. 8	{Entry..... {Air course.....	0	0	.524	.....	.....	.....	.....	.....	.....	75 50 } No.
			0	0	.....	.....	.....	.....	.....	.....	.....	
187	Mar. 10	{Entry..... {Air course.....	0	0	.931	.....	.....	.....	.....	.....	.....	75 100 } No.
			0	0	.....	.....	.....	.....	.....	.....	.....	

a No rib and roof dust samples taken.

b Flame extended through zones.

DISCUSSION OF THE TESTS.

In test 183 the amounts of coal dust and rock dust distributed in the zone were so proportioned that the percentage of coal dust would be 20 per cent. In this test all of the roof was not coated with rock dust and the coal dust was distributed entirely on the floor. The floor samples show an average of 45.1 per cent incombustible material. Inasmuch as it is not known what the relative weights of the pure rock dust on roof and sides and the floor dust were, it is not possible to calculate the average percentage of incombustible in the zone. The flame was not propagated through the zones, extending only to E 1125 (entry) and A 1175 (air course), 125 feet beyond the ignition zone.

In test 185 the ratio attempted in the explosion zone was 23 per cent coal dust to 77 per cent shale dust. The average percentage of incombustible in the road-dust samples was 65.6, whereas that of the rib dust was 84.3, or an average by relative weights of 72.0 per cent. No propagation was obtained, the flame reaching E 1078 and A 1075 only, a maximum of 225 feet beyond the ignition zone.

In test 184 the attempted percentages were 25 per cent coal dust and 75 per cent shale dust. Analyses of samples taken showed an average incombustible content of 63.6 per cent in the road dust and 81.2 per cent in the rib and roof dust, or 70.1 per cent for the section. Complete propagation was obtained with this distribution of shale and coal dusts.

On referring to tests 299 and 306, with Pittsburgh coal and pit shale, it is found that propagation was obtained through a 30 per cent coal dust and 70 per cent shale dust mixture having an incombustible content of 71.8 per cent.

These results indicate that it makes little difference whether the dusts are intimately mixed or the same weight of coal dust is placed on top of the rock dust. Possibly shale placed on the roof is shaken off by the shock wave, and tends to blanket the coal dust to a certain extent so that the cloud raised immediately in advance of the flame is likely to be of a lower coal percentage than the average of the whole. Such mantling of the coal dust with rock dust from the roof would tend to decrease the possibility of an explosion.

In test 188 the shale dust was thrown only on the sides and floor, and coal dust was distributed on the shale, so that the ratio was 30 per cent coal dust and 70 per cent shale dust. Analyses showed an average of 63 per cent incombustible matter. A moderately strong explosion resulted, pressures of 10 and 12 pounds being registered at stations E 1150 and A 1150, respectively, and 20 pounds at station E 950. This explosion was similar in pressures developed to test 152, described on page 172, but the velocities were somewhat greater. The

percentage of combustible in the latter test was 60.2, indicating that a coal-dust mantle resting on rock dust will give about the same pressure effects in an explosion as a slightly greater percentage of coal dust intimately mixed with the shale.

In tests 186 and 187 the coal-dust mantle was of coarser dust. A comparison of the average screen tests of this dust with that used in the other tests of the series, as given below, shows only about one-half as much dust through 100-mesh.

	Fine dust.	Coarse dust.
Through 100-mesh.....per cent..	100.0	48.0
Through 200-mesh.....do.....	88.5	34.0
Through 240-mesh.....do.....	79.0	30.0

In test 186 a 25 per cent coal dust and 75 per cent shale dust loading was attempted, the analyses of samples showing an average incombustible content of 67.1 per cent. No explosion resulted, the decrease in the percentage of fine dust more than offsetting the lower percentage of incombustible dust as compared with test 184.

In the next test (No. 187) the percentage of coal dust was increased to 30, the analyses of samples showing 60.9 per cent incombustible. Even with the increase of coal percentage no explosion resulted, the flame extending only to E 1175 and A 1200, or a maximum distance of 100 feet from the ignition zone.

SUMMARY OF ROCK-DUST TESTS WITH COAL-DUST MANTLES.

A comparison of the propagation tests with standard mixtures and those with coal-dust mantles show that the percentage of shale required to prevent an explosion is practically the same regardless of the method used for distribution. This is probably due to the fact that in an explosion both are thrown into the air at the same time and thoroughly mixed.

EARLY TESTS OF SHALE-DUST ZONES.

Four of the early tests of the second series (Nos. 43, 44, 45, and 46) were made to determine the effect of rock-dust zones of various kinds. All four tests had the same igniting means—namely, the cross-fire of two cannons. One cannon was placed at the face of the main entry in the usual manner, as previously described. The second cannon was placed in the 1250 cut-through, just in by the corner of the cut-through and the entry, and pointed diagonally out and across the main entry. Each cannon was loaded with the standard 4-pound charge of black blasting powder.

The shale used in these tests was pulverized roof shale. The loading was placed on the side shelves and on the floor, no cross shelves being used.

The more important data of these tests are given in Table 51.

TABLE 51.—*Results of early tests of rock-dust zones; coal-dust zones with rock-dust mantle.*

[Originating cause: Standard blown-out shot from two cannons, one being at E 1300 and one at corner of 1250 cut-through, pointing diagonally across the entry.]

Test No.	Date.	Coal-dust zone.			Roof-shale dust zone.		
		Length.	Rate of loading.	Total loading.	Length.	Rate of loading.	Total loading.
43	1913 Sept. 16	Covered benches before cannons.....	Pounds per foot. 50	Pounds 100	(s).....	Pounds per foot. (s)	Pounds (s)
44	Sept. 17	Stations E 1300 to E 900, 400 feet.....	2	800	Stations E 1300 to E 900, 400 feet.....	Δ 25	2, 100
		Benches before cannons.....	50	100			Placed over coal dust and on floor.
45	Sept. 19	Stations E 1300 to E 900, 400 feet.....	2	800	Stations E 900 to E 600, 300 feet.....	4.00	1, 200
		Benches before cannons.....	50	100			Placed on side shelves.
46	Sept. 23	Stations E 1300 to E 500 and E 1250 to A 1050, 1,050 feet.....	2	2, 100	Stations A 1050 to A 750, 300 feet.....	4.50	1, 350
		Benches before cannons.....	50	100			Placed on side shelves, ribs, and roof.
				2, 200			

Test No.	Date.	Maximum pressure.						Time of tin-fol rupture at stations and flame velocity between stations.						Length of flame in shale-dust zone.	Remarks.								
		Station E 1150.		Station E 950.		Station E 750.		Station E 550.		Station E 150.		Fol at station E 1150.				Ve-locity.		Fol at station E 750.		Ve-locity.		Fol at station E 550.	
		Lbs. per sq. in.	4	Lbs. per sq. in.	4	Lbs. per sq. in.	3	Lbs. per sq. in.	2	Lbs. per sq. in.	1	Seconds.	Ft. per sec.			Seconds.	Ft. per sec.	Seconds.	Ft. per sec.	Seconds.	Ft. per sec.	Seconds.	Ft. per sec.	Seconds.
43	1913. Sept. 16																						Was blank test. No shale dust was used, and coal dust on benches only. Flame extended 425 feet into dustless zone.
44	Sept. 17		4	3	2						1.725												Flame extinguished by shale dust over coal dust.
45	Sept. 19		5	3	3						.916	245	1.732	500	2.080							(b)	Flame swept through rock-dust zone and 125 feet outby.
46	Sept. 23	(c)			55	119	12	1.970	(c)					4,444	2.080	1,335	2.210					200	Flame extinguished by rock-dust some in air course by Taftanet barrier in entry.

^a No shale dust used.

^b Flame extended through zone.

^c Flame velocity and pressure curves of test 46 shown in figure 14.

Was blank test. No shale dust was used, and coal dust on benches only. Flame extended 425 feet into dustless zone.

Flame extinguished by shale dust over coal dust.

Flame swept through rock-dust zone and 125 feet outby.

Flame extinguished by rock-dust zone in air course by Taffanel barrier in entry.

Test 44 was made to determine the effect of placing shale dust over coal dust on the side shelves. Previously test 43 was made with coal dust in the first 50 feet only to determine the length of flame from the ignition zone for comparison with test 44 when shale dust was used over coal dust.

In test 43, 50 pounds of pure Pittsburgh coal dust was placed in front of each cannon on a bench. The cut-through and main entry were carefully cleaned with brooms and compressed air. The flame traveled through this dustless zone to E 875, a distance of 425 feet from the face of the entry, as indicated by guncotton being burned.

In test 44 the cannon and the coal-dust loadings on the platforms were the same as in test 43. A 400-foot zone was prepared with shale dust on top of coal dust. Pure coal dust was first placed on the side shelves at the rate of 2 pounds per foot of entry. Roof shale was then placed over the coal dust on the shelves and on the floor at the rate of 5.25 pounds per foot of entry. The percentage of coal in this zone would therefore be 27.6 per cent. In this test the flame extended only to station E 1050, which was 225 feet less than in the previous test with the dustless zone.

Later tests to determine the propagation limits of Pittsburgh coal dust and roof-shale dust with a single entry loading and one igniting shot indicated that this percentage of coal in a mixture with roof shale would not propagate an explosion.

In test 45 pure coal dust was loaded from station E 1300 to station E 900; beyond this was a 300-foot zone of roof-shale dust, this being distributed on the side shelves at the rate of 4 pounds of shale per foot of entry. The flame of the explosion passed through the shale-dust zone but died away at station E 475, 125 feet beyond the shale loading. The pressures developed were very light, the maximum at station E 1150 and at station E 950 being only 5 and 3 pounds, respectively. The weakness of this explosion was probably due to the cut-through and air course having no loading of coal dust. The later tests, 84 to 91, described previously (p. 414), indicated that a side-laden rock dust zone must be nearly twice the length of a coal-dust ignition zone to extinguish an explosion unless the rock dust is placed in barrier form as described in the following chapter.

Test 46 was a public demonstration for the benefit of members of the American Mine Safety Association, mine operators, and State mine inspectors. The arrangements of the test included the use of two cannons for starting the explosion and the employment of both the air course and the main entry. This was one of the first double-entry tests, double-entry loading not being adopted as standard until test 103. The purposes were to test the efficiency of a shale-dust zone in the air course in stopping an explosion, and of a Taffanel

barrier in the main entry in stopping that branch of the explosion. The explosion was most violent and the pressures were unusually high, 119 pounds being recorded at station E 550. The velocity curves of this test are shown in figure 14 (p. 83). The flame from the 350-foot coal-dust zone in the cut-through and air course penetrated only 200 feet into the shale-dust zone. There were no instruments in the air course; hence the pressures developed are not known, but were probably high. In the main entry the flame was extinguished by a Taffanel barrier and a coal-dust zone outby was not ignited. The pressure dropped from 119 pounds at station E 550 to only 12 pounds at station E 150, 400 feet beyond. There were no intermediate manometers. Reference to this test has been previously made on page 82.

**TESTS SHOWING COMPARATIVE EFFECT OF COARSE AND FINE
SIZES OF SHALE DUST ON EXPLOSIBILITY LIMITS.**

A number of tests were made to determine the relative neutralizing effect of 20-mesh shale dust as compared with 100-mesh shale dust when mixed with coal dust.

Tests were made with both pulverized or 100-mesh coal dust and with 20-mesh coal dust. Table 52 gives the principal results of these tests.

TABLE 52.—Results of standard propagation tests showing comparative effect of different sizes of shale dust on explosibility limits.

[Originating cause: Standard blown-out shot from cannon at station E 1300. The ignition zone (pulverized Pittsburgh coal dust) extended from stations E 1300 to E 1260, 50 feet. The mixed dust zones extended from stations E 1260 to E 960, 300 feet; and from stations E 1260 to A 960, 360 feet; total length, 650 feet. Pittsburgh coal dust and pit-shale dust were used.]

Test No.	Date.	Size of coal dust used.		Size of shale dust used.		Mixed dust.			
		Over 95 per cent through—	Percent-age through 200 mesh.	Over 95 per cent through—	Percent-age through 200 mesh.	Ratio of coal dust to shale dust in mixture.	Incom-bustible content.	Rate of loading.	Total loading.
	1916.						Per cent.	Lbs. per ft.	Pounds.
267	Jan. 5...	100 mesh.....	69	100 mesh.....	93	25:75	76.8	8.00	5,200
300	Mar. 17..	do.....	61	do.....	90	25:75	76.4	2.00	1,300
269	Jan. 10..	do.....	74	20 mesh.....	40	25:75	76.9	4.00	2,600
268	Jan. 7...	do.....	73	do.....	40	20:80	81.4	5.00	3,900
273	Jan. 19..	do.....	68	do.....	28	20:80	81.5	4.00	2,600
266	Jan. 3...	20 mesh.....	40	100 mesh.....	97	30:70	73.1	3.33	2,167
270	Jan. 12..	do.....	40	20 mesh.....	27	30:70	72.2	3.33	2,167
271	Jan. 14..	do.....	40	do.....	27	25:75	77.0	4.00	3,600

Test No.	Date.	Records obtained in entry or air course.	Maximum pressures.		Time of tin-foil rupture at stations and flame velocity between stations.						Length of flame in mixed-dust zone.	Propagation obtained.
			Station 1150.	Station 960.	Foil at station 1250.	Velocity.	Foil at station 1150.	Velocity.	Foil at station 1050.	Velocity.	Foil at station 950.	
			Lbs. per sq. in.	Lbs. per sq. in.	Seconds.	Feet per second.	Seconds.	Feet per second.	Seconds.	Feet per second.	Seconds.	Feet.
267	1916. Jan. 5...	{Entry... {Air course...	1 1	2 2	0.308 1.376	56	2.092 1.077	49	4.130			175 225 } No.
300	Mar. 17...	{Entry... {Air course...	3 2	2 2	.441	171	1.027 1.022	79 154	2.285 1.670	147	2.350	225 } Yes. ^b
269	Jan. 10...	{Entry... {Air course...	3 3	2 3	.382	179	.942 1.002	146 161	1.627 1.622	161	2.248 1.909	(*) } Yes.
268	Jan. 7...	{Entry... {Air course...	2 2	1 1	.428	128	1.212 1.519					150 200 } No.
273	Jan. 19...	{Entry... {Air course...	1 1	1 1	.418	44	2.683					100 125 } No.
266	Jan. 3...	{Entry... {Air course...	1 1	2 2	.960	56	2.741 1.709					100 175 } No.
270	Jan. 12...	{Entry... {Air course...	3 1	2 2	.375	168	.969 1.143	68 103	2.435 2.111	207 346	2.917 2.400	(*) } Yes.
271	Jan. 14...	{Entry... {Air course...	2 2	1 1	.273	38	2.908					75 100 } No.

^a Flame extended through zones.

^b In air course, but not in entry.

In test 267 propagation was not obtained with a mixture having 25 per cent of 100-mesh coal dust and 75 per cent of 100-mesh pit-shale dust, the flame extending a maximum of 225 feet into the mixed dust. In test 300 the same percentages and sizes of coal and shale dusts were used; propagation was obtained in the air course, but not in the entry. It will be seen that this mixture is so near the limit that small changes in conditions not controlled will make the difference between partial and complete propagation in one branch of the explosion. In test 269 the percentages of coal and shale dusts were again 25 and 75 per cent, respectively, but 100-mesh coal dust and 20-mesh shale dust, of which 40 per cent would pass through 200-mesh, were used. A weak explosion was obtained.

In tests 268 and 273, 20 per cent of 100-mesh coal dust was mixed with 80 per cent of 20-mesh shale dust. In test 268, 40 per cent of the shale dust would pass 200-mesh, whereas in test 273 only 27 per cent would pass 200-mesh. Propagation was not obtained in either of these tests, the maximum flame extension being 200 feet in the former and 125 feet in the latter.

On comparing the results of the tests it will be seen that the addition of 5 per cent of shale was sufficient to overcome the reduction in the proportion of 200-mesh particles in the shale dust from 90 to 28 per cent.

In test 266, 30 per cent of 20-mesh coal dust, of which 40 per cent would pass 200-mesh, was mixed with 70 per cent of 100-mesh shale dust. Propagation was not obtained, the flame extending a maximum of 175 feet into the mixed dust. In test 270 the size of coal dust and the percentages of coal and shale dust were the same as in test 266, but the shale dust was 20-mesh, 27 per cent of which would pass 200-mesh. Propagation was obtained with low pressures and velocities. In test 271, 25 per cent of 20-mesh coal dust, of which 40 per cent would pass 200-mesh, was mixed with 75 per cent of 20-mesh shale dust, of which 27 per cent would pass 200-mesh. Propagation was not obtained, the flame extending only 100 feet into the mixed dust.

It will be seen that the results with 20-mesh coal dust are the same as with pulverized coal dust. Five per cent of additional shale dust is sufficient to offset the effect of changing from 100-mesh shale dust, of which more than 90 per cent will pass 200-mesh, to 20-mesh shale dust, of which about 30 per cent will pass 200-mesh. The cost of fine grinding will in many places be higher than the cost of additional shale dust. Moreover, the coarser dust has other advantages, as has been previously discussed in this bulletin.

TESTS ON ROCK-DUST ZONES IN THE BUTT ENTRIES.

In connection with the tests to determine the possibility of originating an explosion in a working room, rock-dust zones were formed

in the butt entries. These tests are described beginning on page 354, and the results, including those for the rock-dust zones, are given in Table 42. A brief summary follows.

Rock-dust zones were used in five tests. In two of the tests the flame did not reach the zone, in two tests it reached the zone and was extinguished by the rock dust before the end of the zone was reached, and in one test it apparently traveled through the rock-dust zone and extended beyond.

In this last test there was some question as to the actual extent of the flame. This has been discussed with the results of the test on page 363.

Two of the tests (Nos. 310 and 312) permit a direct comparison showing the effect of a rock-dust zone. Both were originated in No. 3 room and were identical in loading, except that in test 310 there was no rock-dust zone, whereas in test 312 the No. 1 butt was rock-dusted. In test 310, with no rock dust, the flame extended out No. 1 butt and the air course to station A 640, a distance of 390 feet beyond the coal-dust zone. In test 312, with a rock-dust zone, the flame extended to 1B 50, a distance of 130 feet beyond the coal-dust zone. The flame in this test was 260 feet shorter than in test 310. There can be no question as to the general effectiveness of rock-dust zones in extinguishing explosions, but further testing will be necessary in order to determine their exact limitations.

CHAPTER IX.—LIMITATION OF EXPLOSIONS BY BARRIERS.

The use of so-called barriers, or arresting barriers, of various types for stopping coal-dust explosions was one of the logical outgrowths of early tests abroad. The officials in charge of the experiments conducted in the underground gallery at Babitz, near Segengottes, Austria, tried water curtains, but it was found that the kind tested had little effect in checking flames. At the Liévin experiment station, in France, rock-dust barriers were tested by M. Taffanel; from this was developed the employment of a group of cross shelves of the type which has been referred to in Bureau of Mines publications as a Taffanel barrier. The function of these barriers is to launch into the air the rock dust or shale dust on the barriers by the violent air waves which always immediately precede an explosive flame and which, in fact, render a coal-dust explosion possible. The inert dust thus put into the air absorbs heat and physically separates individual particles of coal dust by a screen of incombustible dust. If sufficient inert dust is thus automatically put into the air, it has been found to be efficacious in extinguishing the most violent as well as the weaker explosions. It is absolutely necessary, however, that there be sufficient inert dust to fill the entry completely with a dense cloud of such dust.

The advantage of rock dust as compared with the same quantity of water is one involving the question of time, for if the air waves should upset or in other ways start the flow of water too much in advance of the flame the water, falling to the ground, would be of no avail as a deterrent whereas rock dust that had fallen would again be brought up by the air blast which immediately precedes the flame.

Although the original simple cross-shelf barrier did not always stop an explosion, especially when the explosions were not violent enough to upset the shelves or to blow the rock dust off in sufficiently dense clouds, mechanically operated barriers developed by G. S. Rice at the Bruceton experimental mine have been successful in limiting weak as well as violent explosions.

The Bureau of Mines does not advocate using barriers instead of rendering coal dust inert throughout the mine by water or rock dusting, but regards them as additional precautions.

Should an explosion occur and propagate through a portion of the mine, owing to insufficient treatment of the dust, barriers situated at intervals, particularly where branch entries turn off, would prevent the explosion from going further. The erection of barriers in passages from one mine or section of the mine to another is particularly advisable in preventing the spread of an explosion into the adjoining area, thus possibly saving many lives. If such barriers had been



A. TAFFANEL BARRIER SHELVES INSTALLED IN EXPERIMENTAL MINE.



B. BOX BARRIER, TYPE A, INSTALLED IN EXPERIMENTAL MINE.

installed in the connecting passages of adjacent mines in half a dozen great disasters in the United States, as well as in certain mines in Europe, the loss of hundreds of lives would have been prevented.

TESTS OF TAFFANEL BARRIERS.

The first barrier recommended by Mr. Taffanel consisted of 10 shelves 20 inches wide, placed in entries transversely just beneath the roof, with a center-to-center spacing of about 6 feet, and heaped with rock dust to their full capacity (see Pl. XV, A). Such barriers were installed in many French mines. At a later date the recommended number of shelves was changed from 10 to 15.

In an explosion the rock dust is either swept off the shelves by the air current or is dumped by the overturning or smashing of the shelves, and the dense cloud of dust resulting blankets the flame or cools the gases below ignition temperature.

The Taffanel barrier is so simple in construction that its use would be most desirable except for two disadvantages: First, barriers of this type sometimes fail to operate in low-pressure explosions because the air movement fails to blow off enough dust to blanket the flame; and, second, the exposure of the dust to the air current allows the dusts to become damp at certain seasons of the year if the barriers are installed at points swept by intake air currents. This dampening would prevent the dusts from forming an effective cloud in the event of an explosion. This statement has reference to the mines in the United States. In the deep, hot mines of Europe the seasonal changes have little or no effect underground.

On account of these disadvantages of open-type barriers closed types were invented by the senior author of this bulletin, and they have been tested in many experimental explosions. The construction of these barriers is described in detail in Technical Paper 84, pages 21-42.

RESULTS OF TESTS ON TAFFANEL BARRIERS.

The Taffanel barriers were utilized in many explosion tests to determine the efficiency of barriers of 5 to 15 shelves and, in addition, to limit many of the experimental explosions, because they provided the easiest and cheapest method. When the dust was in place but a couple of days before a test, there was little opportunity for it to become dampened by the air current between the time of installation and the time of the test, and the Taffanel barrier was a convenient means of limiting the explosions. In certain tests the flame did not reach the barrier and the barrier was not disturbed. In others the Taffanel barrier was used to supplement the installation of some other barrier in process of development. Such experiments did not give opportunity for a conclusive test of the Taffanel barrier and have not been included in the accompanying Table 53. This table gives the primary results of each barrier test.

TABLE 53.—Results obtained from tests of Taffanel barriers.

Test No.	Date.	Taffanel barrier.		Flame.		Maximum pressure.				Did barrier stop explosion?	Remarks.
		Position in mine (stations).	Number of shelves.	Kind of dust.	Did explosion reach barrier?	Approximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.	Outby barrier.		
						<i> Ft. per sec.</i>	<i> Feet.</i>	Station.	Pressure.		
								<i> Lbs. per sq. in.</i>	<i> Lbs. per sq. in.</i>		
19-A	1912 Sept. 18	A 1245 to A 1160	15	Shale and ashes.	Yes	...	0	...	...	Yes	Shelves undisturbed; lost small amount of dust.
19-B	do.	do.	15	do.	Yes	...	0	...	...	Yes	Do.
20	Sept. 20	do.	10	Shale	Yes	...	0	...	...	Questionable.	Wooden stoppings in 1250 cut-through. This stopping and the barrier were demolished.
25	Nov. 29	E 550 to E 498	10	do.	No	...	...	...	...	Yes	Flame extended to station E 1025. All shelves except 1, 3, and 5 thrown down.
25	do.	A 1260 to A 1189	10	do.	Yes	...	0	...	...	Yes	Shelves 5, 6, 7, 8, and 10 thrown down.
37	1913 Aug. 6	E 500 to E 440	10	do.	Yes	...	115	E 750	E 360	Yes	Barriers demolished. Auxiliary zone (stations E 440 to E 340) not ignited. Exact flame length uncertain.
38	Aug. 12	do.	10	do.	Yes	...	40	E 750	...	Yes	Auxiliary zone (stations E 440 to E 340) not ignited.
39	Aug. 15	do.	10	do.	Yes	...	65	E 750	E 150	Yes	Do.
40	Sept. 23	do.	10	do.	Yes	3,000	40	E 550	E 150	Yes	Auxiliary zone (stations E 440 to E 340) not ignited.
53	Oct. 31	E 900 to E 840	10	do.	Yes	...	65	E 960	E 750	Yes	Barrier demolished.
55	Dec. 2	E 700 to E 640	11	do.	Yes	6,000	0	E 750	E 550	Yes	Do.
55a	do.	A 1084 to A 1040	8	do.	Yes	...	65	E 750	...	Yes	Some coal dust on surfaces outby barrier. Barrier broken and thrown outby.
56	Dec. 4	E 700 to E 640	10	do.	Yes	500	140	E 750	13	Yes	Large quantity of fine coal dust outby barrier not ignited.
56	do.	A 1100 to A 1074	5	do.	Yes	...	100	...	...	Yes	Flame extended to station E 1075. Shelves not moved; test 2 to 3 inches of dust.
57	Dec. 10	E 700 to E 674	5	do.	No	...	...	...	...	...	Do.
57	do.	do.	5	do.	No	...	...	...	...	...	Do.
57	do.	A 1150 to A 1124	5	do.	Yes	...	25	...	...	Yes	Shelves not moved; test 2 inches of dust.
58	Dec. 12	E 700 to A 640	10	do.	Yes	100	0	E 750	...	Yes	Barrier thrown down, but not much broken.
58	do.	A 1100 to A 1040	10	do.	Yes	...	15	...	...	Yes	Shelves not moved.

58	Dec. 16	E 700 to E 674	5	do.	No.							Flame extended to station E 900. Shelves lost one-half inch of dust.
59	do.	A 1100 to A 1040	10	do.	Yes	0						Shelves lost 2 to 4 inches of dust.
60	Dec. 18	E 700 to E 675	5	do.	No.							Flame extended to station E 925. Shelves lost 3 to 4 inches of dust.
60	do.	A 1100 to 1040	10	do.	Yes	0						Shelves lost 2 to 3 inches of dust.
61	Dec. 22	E 700 to E 640	10	do.	Yes	500	5	E 750	8			First shelf lost two-thirds of dust, rest lost 2 to 3 inches.
61	do.	A 1100 to A 1040	10	do.	Yes							Explosion might have continued had there been dust to feed it.
65	Dec. 29	E 700 to E 640	10	do.	Yes	3,500	190	E 750	65	E 550	15	No.
												Shelves had lost rock dust and picked up coal dust in tests 62 to 64, in which flame reached only station E 1250.
65	do.	A 1100 to A 1040	10	do.	Yes		90					Barrier demolished and scattered.
66	1914. Jan. 2	E 700 to E 640	10	do.	Yes	4,000	340	E 750	63	E 550	35	No.
66	do.	A 1100 to A 1040	10	do.	Yes		40					Barrier failed. Considerable reduction in pressure from stations E 750 to E 550.
67	Jan. 6	E 700 to E 640	10	do.	Yes	2,000	40	E 750	51	E 550	18	Yes.
67	do.	A 1100 to A 1040	10	do.	Yes		0					Barrier demolished and scattered.
72	Jan. 15	E 700 to E 640	10	Limestone	No.							Do.
72	do.	A 1100 to A 1040	10	Shale	Yes		0					Do.
72	Jan. 19	E 700 to E 640	10	Limestone	Yes	300	0	E 750	0	E 550	0	Yes.
73	do.	A 1100 to A 1040	10	Shale	Yes		0					Shelves lost 3 to 4 inches of dust.
74	Jan. 21	do.	10	do.	Yes		65					First shelf lost practically all its dust, rest lost a less amount.
												Barrier had lost shale and picked up soot in previous explosions. Did not lose much dust in this test.
76	Jan. 26	E 700 to E 640	10	Limestone	Yes	1,500	0	E 750	30	E 550	2	Yes.
76	do.	A 1100 to A 1040	10	Shale	Yes		90					Auxiliary zone (stations E 640 to E 440) not ignited. Barrier demolished and scattered.
77	Jan. 28	A 1066 to A 1040	5	do.	Yes		140					Barrier thrown down.
78	Jan. 29	do.	5	do.	Yes		0					Failure due to small number of shelves; only one dislodged.
78	Feb. 2	A 1100 to A 1040	10	do.	Yes		90					Barrier demolished.
80	Feb. 3	A 1100 to A 1062	7	do.	Yes		285					Seven shelves not sufficient to stop a strong explosion.
81	Feb. 4	E 700 to E 640	10	Limestone	Yes	150	215	E 750	8	E 550	3	No.
81	do.	A 1100 to A 1040	10	Shale	Yes		65					Barrier thrown down. Explosion checked, but not extinguished.
83	Feb. 6	E 700 to E 640	10	Limestone	Yes	4,000	90	E 750	58	E 550	9	Yes.
												Barrier demolished.
												Auxiliary zone (stations E 640 to E 440) not ignited. Barrier demolished.

^a These tests are illustrated by graphs as indicated: Test 46, figure 14; test 55, figure 56; test 81, figure 55; test 91, figure 58; test 148, figure 77; test 202, figure 59; test 330, figure 78; test 347, figure 60; test 368, figure 61; test 391, figure 73; test 404, figure 66; test 439, figure 70; test 466, figure 76.

TABLE 53.—*Results obtained from tests of Tafanel barriers—Continued.*

Test No.	Date.	Tafanel barrier.		Did explosion reach barrier?	Flame.		Maximum pressure.				Did barrier stop explosion?	Remarks.
					Length beyond barrier.	Inby barrier.	Outby barrier.					
		Position in mine (stations).	Num-ber of shelves.				Kind of dust.	Ap-prox-imate velocity on reach-ing barrier.	Station.	Pres-sure.		
83 86	1914. Feb. 6 Feb. 13	A 1100 to A 1040. E 200 to E 140.	10 10	Shale Limestone	Yes No.	<i>Pt. per sec.</i> 65				<i>Lbs. per sq. in.</i>	Yes	Barrier demolished. Flame extended to station E 800. Barrier de-molished. Flame was stopped by rock-dust zone.
87 91a 93	Feb. 16 Feb. 20 Feb. 24 Mar. 4	A 1100 to A 1046. E 700 to E 640. A 1100 to A 1040. A 1100 to A 1074.	9 10 10 5	Shale do Limestone Shale	Yes Yes Yes Yes	70 15 65 125	E 750	49	E 550	13	Yes Yes Yes No.	Barrier demolished. Do. Do. Probably a failure; not enough shelves.
94 95 101 102	Mar. 6 Mar. 10 Mar. 25 Mar. 31	do. E 200 to E 140. E 700 to E 640. E 200 to E 140.	5 10 10 10	do Limestone Shale do	Yes Yes Yes No.	175 0 140	E 350 E 750	41 30			No. Yes Yes	Five shelves not sufficient to stop explosion. Barrier demolished. Do. Flame extended to station E 800. Barrier de-molished.
104	Apr. 16	A 947 to A 891.	10	do	Yes	780	E 950	20	E 750	10	Yes	Barrier demolished.
108 140	Apr. 21 Oct. 1	do. 1B 280 to 1B 234.	10 10	Limestone Shale	Yes Yes	100 10					Yes Yes	Do. Rock dust from stopping in 200 cut-through may have assisted barrier in checking explosion. First five shelves thrown down. Others re-mained up.
141	Oct. 9	1B 285 to 1B 205.	15	do	Yes	0					Yes	Barrier broken. Barrier demolished.
145 146a	Nov. 9 Dec. 4	E 947 to E 893. 1B 280 to 1B 232.	10 10	Limestone do	Yes Yes	1,000 0	E 950	14	E 750	9	Yes Yes	Barrier thrown down and partly broken. Do. Flame extended to station E 1175. Barrier thrown down.
166 167	1915. Jan. 28 Jan. 29	E 948 to E 891. do. E 948 to E 891.	10 10 10	Shale do do	Yes Yes No.	60 0 0	A 950	7	E 750 A 750	2 4	Yes Yes	Barrier thrown down and partly broken. Do. Flame extended to station E 1175. Barrier thrown down.
167	do.	A 948 to A 891.	10	do	No.							Barrier thrown down.

206	Apr. 24	E 948 to E 960	10	do.	Yes	550	0	E 960	10	E 750	4	Yes	Barrier demolished.
207	do.	A 948 to A 960	10	do.	Yes	550	0	A 960	17	E 750	11	Yes	Do.
208	Apr. 27	E 945 to E 967	10	do.	Yes	100	0						Three shelves thrown down. 1.2 per cent gas in air current.
209	do.	A 947 to A 968	10	do.	Yes		0	A 960	5	A 750	0	Yes	Barrier thrown down. 1.2 per cent gas in air current.
210	Apr. 29	E 947 to E 960	10	do.	Yes	600	0						Barrier demolished and scattered. 2.4 per cent gas in air current.
211	do.	A 947 to A 960	10	do.	Yes	5,000	10	A 960	53	A 750	27	Yes	Do.
212	May 3	E 947 to E 960	10	do.	Yes	35	0	E 960	1	E 750	1	Yes	Shelves not moved; lost about 2 inches of dust. 2.2 per cent gas in air current.
213	do.	A 947 to A 960	10	do.	Yes	300	0	A 960	1	A 750	0	Yes	Do.
214	May 6	E 947 to E 960	10	do.	Yes	1,000	0	E 960	11	A 750	0	Yes	Barrier demolished.
215	do.	A 947 to A 960	10	do.	Yes	1,000	0	E 960	14	E 750	4	Yes	Do.
216	May 10	E 947 to E 960	10	do.	Yes	400	0	E 960	1	E 750	1	Yes	Shelves lost about 3 inches of dust; 0.8 per cent gas in air current.
217	do.	A 947 to A 960	10	do.	Yes		0						Do.
218	May 11	E 947 to E 960	10	do.	Yes	380	0	A 960	2	A 750	0	Yes	Three shelves thrown down.
219	do.	A 947 to A 960	10	do.	Yes	550	0	E 960	5	E 750	2	Yes	Barrier thrown down.
220	May 12	E 947 to E 960	10	do.	Yes	1,300	15	E 960	15	E 750	4	Yes	Barrier demolished; 2.7 per cent gas in air current.
221	do.	A 947 to A 960	10	do.	Yes	2,000	0	A 960	17	A 750	0	Yes	Do.
222	May 20	E 947 to E 960	10	do.	Yes	500	0	E 960	14	E 750	4	Yes	Barrier demolished; 2.1 per cent gas in air current.
223	do.	A 947 to A 960	10	do.	Yes	1,000	0	A 960	14	A 750	0	Yes	Do.
224	Oct. 22	E 947 to E 960	10	do.	Yes	2,400	0	E 960	12	E 750	0	Yes	Barrier demolished; 2.3 per cent gas in air current.
225	do.	A 947 to A 960	10	do.	Yes	1,700	0	A 960	21	E 750	2	Yes	Do.
226	Oct. 27	E 947 to E 960	10	do.	Yes	60	0	E 960	7	E 750	3	Yes	Seven shelves thrown down; 1 per cent gas in air current.
227	do.	A 947 to A 960	10	do.	Yes		0						Do.
228	Nov. 16	E 947 to E 960	10	do.	Yes	420	0	A 960	6	A 750	1	Yes	Barrier demolished; 1 per cent gas in air current.
229	do.	A 947 to A 960	10	do.	Yes	760	0	E 960	27	E 750	1	Yes	Barrier demolished and scattered.
230	Nov. 24	E 947 to E 960	10	do.	Yes	40	0	A 960	3	E 750	3	Yes	Barrier not moved; lost considerable dust.
231	Nov. 30	E 947 to E 960	10	do.	Yes	300	0	E 960	3	E 750	3	Yes	Barrier thrown down.
232	do.	A 947 to E 960	10	do.	Yes	500	0	E 960	7	E 750	3	Yes	One shelf flat up.
233	Dec. 1	E 947 to E 960	10	do.	Yes	1,000	0	A 960	13	A 750	3	Yes	Barrier demolished.
234	do.	A 947 to E 960	10	do.	Yes	170	0	E 960	170	E 750	1	Yes	Barrier not moved; lost one-half of dust.
235	Dec. 6	E 947 to E 960	10	do.	Yes	300	0	A 960	2	E 750	1	Yes	Shelves 1 to 3 flat up; others thrown down.
236	do.	A 947 to E 960	10	do.	Yes	160	0	E 960	1	E 750	1	Yes	Barrier not moved; lost a little dust.
237	Dec. 9	E 947 to E 960	10	do.	No	700	0	A 960	3	A 750	1	Yes	Do.
238	do.	A 947 to E 960	10	do.	No								Flame extended to station E 1050. Barrier undisturbed.
239	Dec. 10	E 947 to E 960	10	do.	Yes	420	25	E 960	4	E 750	3	Yes	Flame extended to station A 1000. Frame under shelves 6 to 10 collapsed.
240	do.	A 947 to E 960	10	do.	Yes								Shelves 1, 2, 4, and 5 left up, with some dust on them.

* These tests are illustrated by graphs as indicated: Test 55, figure 14; test 55, figure 56; test 81, figure 55; test 91, figure 58; test 148, figure 77; test 262, figure 59; test 330, figure 78; test 347, figure 60; test 358, figure 61; test 391, figure 73; test 404, figure 66; test 439, figure 70; test 466, figure 76.

TABLE 53.—Results obtained from tests of Taffanel barriers—Continued.

Test No.	Date.	Taffanel barrier.		Flame.		Maximum pressure.				DId barrier stop ex- plosion?	Remarks.
						Inby barrier.		Outby barrier.			
						Station.	Pres- sure.	Station.	Pres- sure.		
		Position in mine (stations).	Num- ber of shelves.	KInd of dust.	DId ex- plosion reach barrier?	A p- proxi- mate reach velocity on barrier.	Length beyond barrier.	Lbs. per sq. in.	Lbs. per sq. in.		
257	1915. Dec. 10	A 947 to A 893	10	Shale	Yes	Ft. per sec. 1,250	Fed. 0	A 950 12	A 750	Yes	Barrier demolished.
258	Dec. 13	E 947 to E 893	10	do.	Yes	200	0	E 950 2	E 750	Yes	Barrier not moved; lost a little dust.
259	do.	A 947 to A 893	10	do.	Yes	250	0	A 950 4	A 750	Yes	Two shelves thrown down.
260	Dec. 17	E 947 to E 893	10	do.	Yes	300	0	E 950 11	E 750	Yes	Barrier demolished and scattered.
261	do.	A 947 to A 893	10	do.	Yes	1,700	0	A 950 16	A 750	3	Do.
262	Dec. 20	E 947 to E 893	10	do.	Yes	1,000	0	E 950 10	E 750	3	All shelves thrown down except No. 3.
263	Dec. 22	do.	10	do.	Yes	2,300	15	E 950 42	E 750	9	Barrier demolished and scattered.
264	Dec. 23	do.	10	do.	Yes	140	0	E 950 1	E 750	1	Barrier not moved.
265	Dec. 28	do.	10	do.	Yes	100	0	E 950 1	E 750	1	Do.
266	Dec. 30	do.	10	do.	Yes	310	0	E 950 3	E 750	2	Shelf 3 thrown down; others not moved.
269	1916. Jan. 10	do.	10	do.	Yes	170	0	E 950 2	E 750	1	Barrier not moved; lost a little dust.
270	Jan. 12	do.	10	do.	Yes	240	0	E 950 1	E 750	1	Barrier not moved.
274	Jan. 21	do.	10	do.	Yes	1,000	0	E 950 15	E 750	3	Barrier demolished and scattered.
275	Jan. 24	do.	10	do.	Yes	300	0	E 950 7	E 750	2	Shelves 1, 3, 5, and 6 thrown down.
277	Jan. 28	do.	10	do.	Yes	280	50		E 750	1	Action of barrier uncertain.
279	Feb. 1	do.	10	do.	No.						Flame extended to station E 1000. Barrier not disturbed. 1.9 per cent gas in air current.
279	do.	A 947 to A 893	10	do.	No.						Flame extended to station A 1022. No. 1 shelf thrown down and broken. 1.9 per cent gas in air current.
280	Feb. 3	E 947 to E 893	10	do.	Yes	190	0	E 950 2	E 750	1	Barrier not moved. 2.2 per cent gas in air current.
282	Feb. 5	do.	10	do.	Yes	500	0	E 950 7	E 750	2	Shelves 1, 2, 3, and 5 not thrown down; these scattered most of their dust.

Barrier demolished.
Barrier not moved; lost a little dust.
Two shelves thrown down.
Barrier demolished and scattered.
Do.
All shelves thrown down except No. 3.
Barrier demolished and scattered.
Barrier not moved.
Do.
Shelf 2 thrown down; others not moved.
Barrier not moved; lost a little dust.
Barrier not moved.
Barrier demolished and scattered.
Shelves 1, 3, 5, and 6 thrown down.
Action of barrier uncertain.
Flame extended to station E 1000. Barrier not disturbed. 1.9 per cent gas in air current.
Flame extended to station A 1028. No. 1 shelf thrown down and broken. 1.9 per cent gas in air current.
Barrier not moved. 2.2 per cent gas in air current.
Shelves 1, 2, 3, and 5 not thrown down; these retained most of their dust.

264	Feb. 9	do.	10	do.	Yes.	70	0		E 750	2	Yes	Barrier thrown down; dust in piles on floor. 0.8 per cent gas in air current.
265	Feb. 14	do.	10	do.	Yes.	150	0	E 950	E 750	2	Yes	Barrier not moved; lost a little dust. 1.6 per cent gas in air current.
266	Feb. 15	do.	10	do.	Yes.	330	0	E 950	E 750	2	Yes	All shelves down except Nos. 3 and 6; dust in piles. 0.8 per cent gas in air current.
268	Feb. 19	do.	10	do.	Yes.	75	0	E 950	E 750	2	Yes	Shelves not moved; lost some dust.
269	Feb. 24	do.	10	do.	Yes.	220	0	E 950	E 750	2	Yes	Barrier demolished and scattered. Cross shelves had been loaded in addition.
330a	May 28	A 945 to A 1005	5	do.	Yes.	260	0	A 950	E 750	2	Yes	Barrier demolished and scattered.
334	Oct. 16	E 947 to A 983	10	do.	Yes.	720	0	A 950	A 750	8	Yes	Barrier demolished and scattered.
336	Oct. 24	E 947 to E 983	10	do.	Yes.	200	0	E 950	E 750	1	Yes	Barrier not moved; lost a little dust.
336	do.	A 947 to A 983	10	do.	Yes.	800	0	A 950	A 750	2	Yes	Shelves 1, 5, and 6 thrown down; dust in piles on floor.
339	Oct. 30	E 947 to E 983	10	do.	Yes.	1,000	0	E 950	E 750	6	Yes	Shelves 1 to 4 remained up; others thrown down; dust in piles.
339	do.	E 947 to A 983	10	do.	Yes.	1,000	0	A 950	A 750	2	Yes	Barrier thrown down, considerably broken.
343	Nov. 13	E 947 to E 983	10	do.	Yes.	1,200	0	E 950	E 750	7	Yes	Barrier demolished and scattered.
345	do.	A 947 to A 983	10	do.	Yes.	1,000	0	A 950	A 750	5	Yes	Do.
346	Nov. 15	E 947 to E 983	10	do.	Yes.	1,700	0	E 950	E 750	11	Yes	Barrier demolished.
346	do.	A 947 to A 983	10	do.	Yes.	2,000	0	A 950	A 750	13	Yes	Barrier demolished and scattered 600 feet outby.
347a	Nov. 17	do.	10	do.	Yes.	5,000	0	A 950	A 750	33	Yes	Photographic record showed no flame outby station 1, 900.
349	Nov. 22	E 947 to E 983	10	do.	Yes.	1,000	0	E 950	E 750	5	Yes	Shelves 5, 9, and 10 thrown down and broken.
349	do.	A 947 to A 983	10	do.	Yes.	350	0	A 950	A 750	2	Yes	Shelves all thrown down except No. 4.
350	Nov. 24	E 947 to E 983	10	do.	Yes.	550	0	E 950	E 750	8	Yes	Barrier demolished.
350	do.	A 947 to A 983	10	do.	Yes.	1,100	0	A 950	A 750	5	Yes	Do.
352	Nov. 28	E 947 to E 983	10	do.	Yes.	260	0	E 950	E 750	5	Yes	Shelves 6 and 7 only ones down; dust in piles.
352	do.	A 947 to A 983	10	do.	Yes.	830	0	A 950	A 750	3	Yes	Barrier demolished.
354	Dec. 4	E 947 to E 983	10	do.	Yes.	100	0	E 950	E 750	3	Yes	Barriers not moved; lost some dust.
354	do.	A 947 to A 983	10	do.	Yes.	320	15	A 950	A 750	2	Yes	Barrier demolished.
355	Dec. 6	E 947 to E 983	10	do.	Yes.	250	180	E 950	E 750	4	No.	Barrier failed. Shelves lost one-half of loading, otherwise undisturbed.
355	do.	A 947 to A 983	10	do.	Yes.	300	515	A 950	A 750	2	No.	Barrier failed. No. 5 shelf down and broken; others up but lost four-fifths of dust.
356	Dec. 8	E 947 to E 983	10	do.	Yes.	2,500	0	E 950	E 750	35	Yes	Barrier demolished and scattered.
356	do.	A 947 to A 983	10	do.	Yes.	4,500	0	A 950	A 750	48	Yes	Do.
357	Dec. 11	E 947 to E 983	10	do.	Yes.	360	0	E 950	E 750	4	Yes	Shelves 5, 6, 7, and 9 down and broken; others lost about one-half of dust.
357	do.	A 947 to A 983	10	do.	Yes.	450	0	A 950	A 750	2	Yes	Barrier thrown down and somewhat broken; dust in piles.
358a	Dec. 13	E 947 to E 983	15	do.	Yes.	4,500	0	E 950	E 750	27	Yes	Barrier demolished and scattered to pit mouth.

^a These tests are illustrated by graphs as indicated: Test 46, figure 14; test 55, figure 56; test 81, figure 55; test 91, figure 56; test 148, figure 77; test 262, figure 59; test 330, figure 78; test 347, figure 60; test 355, figure 61; test 391, figure 73; test 404, figure 66; test 439, figure 70; test 466, figure 76.

TABLE 53.—Results obtained from tests of Taffanel barriers—Continued.

Test No.	Date.	Taffanel barrier.		Did explosion reach barrier?	Flame.	Maximum pressure.				Remarks.		
		Position in mine (stations).	Num-ber of shelves.			Kind of dust.	Inby barrier.		Outby barrier.			
							Length beyond barrier.	Station.	Pressure.		Station.	Pressure.
				Ap-proximate velocity on reach-ing barrier.	Feet.	Lbs per sq. in.	Lbs per sq. in.	Lbs per sq. in.	Did barrier stop ex-plosion?			
360	1916, Dec. 18	E 947 to E 893	10	Shale	Yes	1,100	0	E 950	12	E 750	Yes	Barrier demolished. Do.
360	do.	A 947 to A 893	10	do.	Yes	830	0	A 930	18	A 750	Yes	
361	Dec. 20	E 947 to E 893	10	do.	Yes	620	0	E 950	10	E 750	6	Do. Barrier demolished and scattered. Shelves Nos. 1, 2, 3, 4, and 8 remained in place, but lost one-half to two-thirds of their dust.
361	Dec. 20	A 947 to A 893	10	do.	Yes	600	0	A 930	13	A 750	3	
362	Dec. 22	E 947 to E 893	10	do.	Yes	600	0	E 950	9	E 750	6	Barrier demolished. Barrier not moved, lost a little dust.
362	do.	A 947 to A 893	10	do.	Yes	720	15	A 950	9	A 750	4	
363	Dec. 27	E 947 to E 893	10	do.	Yes	50	0	E 960	2	E 750	2	Barrier demolished.
363	do.	A 947 to A 893	10	do.	Yes	130	0	A 960	2	A 750	1	
365	1917, Jan. 3	E 947 to E 893	10	do.	Yes	800	0	E 960	14	E 750	9	Shelves all thrown down except No. 1, which lost most of its dust.
365	do.	A 947 to A 893	10	do.	Yes	1,300	0	A 960	13	A 750	4	
366	Jan. 5	E 947 to E 893	10	do.	Yes	450	0	A 960	8	E 750	6	Barrier demolished. Shelves Nos. 6, 8, 9, and 10 thrown down. 1 per cent gas in air current.
366	do.	A 947 to A 893	10	do.	Yes	820	0	A 960	8	A 750	2	
370	Jan. 12	do.	10	do.	Yes	650	0	A 960	18	A 750	3	Do. Barrier demolished.
371	Jan. 16	E 947 to E 893	10	do.	Yes	3,700	0	E 960	35	E 750	10	
372	Jan. 18	do.	10	do.	Yes	65	0	E 960	1	E 750	1	Barrier not moved; lost one-fourth to one-third of dust. Barrier not moved; lost one-half to one-third of dust.
372	do.	A 947 to A 893	10	do.	Yes	330	0	A 960	1	A 750	1	
373	Jan. 19	E 947 to E 893	10	do.	Yes	450	0	E 960	12	E 750	9	Shelves Nos. 5, 7, 8, and 10 thrown down; others lost one-third of their dust.
373	do.	A 947 to A 893	10	do.	Yes	1,100	0	A 960	11	A 750	2	

378	Feb. 1	E 150 to E 102	9	do.....	Yes...	550	0	E 150	10	E 750	10	Yes	Barrier demolished and thrown out of pit mouth. Barrier demolished and scattered. 1.5 per cent gas in air current.
383	Feb. 27	E 947 to E 883	10	do.....	Yes...	500	0	E 950	19	E 750	10	Yes	Do.
383	do.....	A 947 to A 883	10	do.....	Yes...	1,000	0	A 950	28	A 750	8	Yes	All shelves down except Nos. 2, 3, and 4; these lost one-half of their dust.
384	Mar. 1	E 947 to E 883	10	do.....	Yes...	800	0	E 950	11	E 750	9	Yes	Barrier demolished.
384	do.....	A 947 to A 883	10	do.....	Yes...	900	0	.....	.....	A 750	2	Yes	All shelves down and broken except No. 2. 2.3 per cent gas in air current.
385	Mar. 2	E 947 to E 883	10	do.....	Yes...	1,100	0	E 950	9	E 750	5	Yes	Barrier demolished. 2.3 per cent gas in air current.
385	do.....	A 947 to A 889	9	do.....	Yes...	1,000	15	A 950	8	A 750	4	Yes	Barrier demolished and scattered.
391 ^a	Mar. 9	A 947 to A 883	10	do.....	Yes...	350	0	E 950	26	E 750	1	Yes	Barrier not moved; lost a little dust.
394	Mar. 14	E 947 to A 883	10	do.....	Yes...	100	0	E 950	2	E 750	1	Yes	Shelves up except No. 1. Shelves lost some dust.
394	do.....	A 947 to A 883	10	do.....	Yes...	170	0	A 950	2	A 750	1	Yes	Shelves all thrown down except No. 2. 1.5 per cent gas in air current.
395	Mar. 15	E 947 to E 883	10	do.....	Yes...	500	0	E 950	9	E 750	6	Yes	Barrier demolished. 1.5 per cent gas in air current.
395	do.....	A 947 to A 883	10	do.....	Yes...	550	15	A 950	8	A 750	4	Yes	Flame extended to station E 975. Barrier not moved; lost a little dust. 2.2 per cent gas in air current.
396	Mar. 20	E 947 to E 883	10	do.....	No.....	.....	.....	.....	.....	.....	.....	.....	First eight shelves thrown down and broken; other two left up, but lost one-half of their dust 2.2 per cent gas in air current.
396	do.....	A 947 to A 883	10	do.....	Yes...	100	0	A 950	1	A 750	1	Yes	Barrier demolished.
404 ^a	Mar. 30	E 947 to E 883	10	do.....	Yes...	1,100	0	E 950	20	E 750	10	Yes	Barrier not moved; lost some dust. Explosion probably stopped for lack of fuel.
404	do.....	A 947 to A 883	10	do.....	Yes...	2,000	0	A 950	24	A 750	4	Yes	Barrier demolished.
406	Apr. 3	E 947 to E 883	10	do.....	Yes...	230	40	E 950	5	E 750	3	No.	Shelves all down except Nos. 3, 4, 5, and 10. 1.7 per cent gas in air current.
406	do.....	A 947 to A 883	10	do.....	Yes...	500	0	A 950	6	A 750	2	Yes	Barrier demolished.
408	Apr. 6	E 947 to E 883	10	do.....	Yes...	100	0	E 950	6	E 750	5	Yes	Barrier demolished. 1.7 per cent gas in air current.
408	do.....	A 947 to A 883	10	do.....	Yes...	300	15	A 950	6	A 750	2	Yes	Shelves Nos. 5, 6, and 7 thrown down; others lost most of their dust.
409	Apr. 9	E 947 to E 883	10	do.....	Yes...	650	0	E 950	9	E 750	7	Yes	Barrier demolished.
409	do.....	A 947 to A 883	10	do.....	Yes...	800	0	A 950	9	A 750	2	Yes	Barrier demolished and thrown out of pit mouth.
416	Apr. 18	E 150 to E 96	10	do.....	Yes...	600	85	E 150	19	.....	.....	No.	Explosion continued too long to be checked by the barrier.
416	do.....	E 883 to E 947	10	do.....	Yes...	1,500	0	.....	.....	E 950	54	Yes	Barrier demolished and carried to face of entry.
425	May 8	A 905 to A 934	9	do.....	Yes...	.....	0	2B 50	2	A 950	1	Yes	Shelf No. 5 thrown down; others lost small amount of dust.
426	May 9	do.....	9	do.....	Yes...	.....	0	2B 50	2	A 950	1	Yes	Barrier not moved; lost a little dust.

^a These tests are illustrated by graphs as indicated: Test 46, figure 14; test 55, figure 56; test 81, figure 55; test 91, figure 58; test 148, figure, 77; test 262, figure 59; test 330, figure 78; test 347, figure 60; test 358, figure 61; test 391, figure 73; test 404, figure 70; test 466, figure 76.

TABLE 53.—Results obtained from tests of Taffanel barriers—Continued.

Test No.	Date.	Taffanel barrier.		Did explosion reach barrier?	Flame.	Maximum pressure.				Remarks.		
		Position in mine (stations).	Num-ber of shelves.			Kind of dust.	Inby barrier.		Outby barrier.		Did barrier stop ex-plosion?	
							Station.	Pres-sure.				Station.	Pres-sure.
					Ap-proxi-mate velocity on reach-ing barrier.	Length beyond barrier?	Lbs. per sq. ft.	Lbs. per sq. in.				
429	1917.	A 905 to A 954.	9	Shale	Yes	80	2B 50	2	A 930	1	Yes	Barrier not moved; lost a little dust. Barrier not moved; lost a little dust. Flame apparently passed under barrier. Do. All shelves undisturbed except No. 6, which was thrown down.
430	May 17	do.	9	do.	Yes	100	2B 50	1	A 930	1	No.	
430	do.	A 747 to A 693.	10	do.	Yes	100	A 750	1			No.	
432	May 24	A 947 to E 903.	10	do.	Yes	270	E 940	6	E 750	2	No.	
432	do.	A 947 to A 903.	10	do.	Yes	300	A 950	6	A 750	2	Yes	Barrier demolished. Shelf No. 1 only one thrown down; all the other shelves lost a little dust. 1.8 per cent gas in air current.
431	Dec. 11	E 947 to E 903.	10	do.	Yes	100	E 950	2	E 750	1	Yes	
434	do.	A 947 to A 903.	10	do.	Yes	200	A 950	2	A 750	1	Yes	Barrier demolished. 1.8 per cent gas in air current. Flame extended to station E 1050. Barrier not disturbed. 1.9 per cent gas in air current. Shelves Nos. 1, 2, 5, 6, and 7 thrown down. 1.9 per cent gas in air current. Shelves Nos. 1, 2, 5, and 8 left up; others thrown down. 0.9 per cent gas in air current.
437	Dec. 20	E 947 to E 903.	10	do.	No.							
437	do.	A 947 to A 903.	10	do.	Yes	100	A 950	1	A 750	1	Yes	
439	Dec. 28	E 947 to E 903.	10	do.	Yes	340	E 950	8	E 750	4	Yes	
442	1918.											Shelves not moved; lost a little dust. Do. Shelves not moved; lost a little dust. Fall at station A 550 fused. Flame passed barrier. Barrier demolished. 1.1 per cent gas in air current. Barrier demolished.
442	Mar. 7	A 675 to A 621.	10	do.	Yes	100	A 750	1			Yes	
445	Mar. 13	do.	10	do.	Yes	100	A 750	1			Yes	
446	Mar. 15	do.	10	do.	Yes	200	A 750	1			No.	
447	May 10	A 947 to A 903.	10	do.	Yes	500	A 950	8	A 750	2	Yes	
449	May 11	do.	10	do.	Yes	1,000	A 950	14	A 750	3	Yes	

^a These test were illustrated by graphs as indicated: Test 49, figure 14; test 55, figure 56; test 81, figure 55; test 91, figure 58; test 148, figure 77; test 202, figure 59, test, 330; figure 76; test 347, figure 60; test 354, figure 61; test 391, figure 78; test 404, figure 62; test 426, figure 76; test 436, figure 76; test 456, figure 76.

In all, 135 tests, involving 207 barriers, have been tabulated. Of these barriers, 173 stopped the flame successfully, 15 were not successful, 4 could not be proved to have stopped the flame, and 15 were not reached by the flame.

The decision as to whether or not the barrier was operated successfully depends on the study of several kinds of evidence. The points considered are as follows: The length of flame through or beyond the barrier, as determined by guncotton, matches, tin-foils, photographic paper, or other flame indicators; the reduction of pressure, as obtained from pressures inby and outby the barrier; the distances barrier shelves and contents are projected by the explosion; the amount of dust blown from the shelves when they are not dislodged from position; the condition of the entry beyond the barrier with regard to the presence of coal dust, rock dust, or moisture; the ignition or nonignition of coal-dust zones outby the barrier when such zones are used, and the probable length of the flame of the explosion were no barrier present. Not all of these points have been tabulated, but they have been considered in making the decision as to the success of the barrier.

In some tests there was no question as to the result, as there was no indication of flame beyond the original position of the barrier; more especially, if there was a coal-dust zone outby the barrier, its nonignition indicated even more conclusively the quenching effect of the barrier. Whenever the guncotton tufts were consumed for 100 feet or more beyond the barrier, the study of other factors was necessary. In several such cases where the operation was considered successful the barrier shelves and dust were projected considerably outby their original position; therefore it is possible that due to this movement the quenching action on the flame of the explosion did not become effective for some distance beyond the original position of the barriers. If there were coal dust outby the barrier, and the burning of the guncotton took place only for 100 to 150 feet beyond the barrier, nonignition of the coal dust would indicate that the barrier was successful.

The number of shelves used for most of these tests was 10. The average capacity of a shelf was about 4 cubic feet, with a weight of rock dust of about 300 pounds. Ten shelves would, therefore, have a total rock-dust loading of 3,000 pounds. The average cross section of the entry at points where the barriers were tested was 60 square feet. The amount of dust per square foot of entry section would therefore be 50 pounds. If 15 shelves are used, as seems desirable, the amount of dust per square foot of entry would then be 75 pounds. It is believed to be desirable so to construct the barriers as to have at least this amount of dust per square foot. If Taffanel barriers are installed in entries of larger cross section, it is desirable that

larger barriers be used, so that the above ratio of dust distribution may be maintained.

The pressures recorded near the barriers in tests in which the explosion was successfully limited ranged from about 1 pound to 127 pounds per square inch. The results of the tests with high pressures are more conclusive than those with lower pressures, since the reduction of pressure in the former tests is good evidence of quenching effect. On the contrary, in tests of very low pressure the responsibility of the barriers for limiting the explosion can not be proved, for the explosion may have been traveling so slowly that it would have died away within a short distance had no barrier been present. Test 46, with a reduction from 119 pounds at station E 550 to 12 pounds at station E 150; test 55, with a reduction from 72 pounds at station E 750 to 16 pounds at station E 550; test 76, with a reduction from 30 pounds at station E 750 to 2 pounds at station E 550, and test 83, with a reduction from 58 pounds at station E 750 to 9 pounds at station E 550, are particularly interesting as showing the rapid dying away of pressure when the barrier operates successfully. Nos. 207, 209, and 213 are examples of tests in which slow-moving flame was supposedly quenched by the dust from the barrier; in the latter two tests the shelves were not thrown down, only a small quantity of dust being blown from the shelves. Test 38 gave a pressure of 3 pounds at station E 750. The auxiliary zone outby the barrier was not ignited by the flame; notwithstanding the low pressure at station E 750, the shelves were thrown down by the explosion; however, the pressure at the barrier may have been considerably higher than 3 pounds.

In general, pressures over 10 pounds per square inch will throw down and break the shelves; for lower pressures the shelves may remain in position and then the effectiveness of the barrier depends on the amount of dust blown off the shelves by the air current.

FAILURES.

In test 65 the flame, as indicated by the guncottons, extended 190 feet beyond the barrier. This was not a fair test, as the barrier had lost considerable dust in previous tests in which extensive explosions had not occurred and the rock dust had been contaminated by coal dust.

In test 66 the flame, as indicated by the guncottons, extended 340 feet beyond the barrier. Had there been a coal-dust zone beyond the barrier, it would have been ignited in all probability. However, it is interesting to note that the pressure at station E 550—35 pounds—is much less than the pressure of 63 pounds at station E 750. If there had been 15 shelves instead of 10 in this test, in all

probability the reduction of pressures would have been greater and the explosion would have been stopped.

In test 77 a five-shelf barrier in the air course seemingly failed to stop the explosion, the flame, as indicated by guncottons, extending 140 feet beyond the barrier. Inasmuch as only one of the five shelves was dislodged, the quenching of the flame was probably not due to the barrier.

In test 80 the flame extended 285 feet beyond the seven-shelf barrier in the air course. In all probability the barrier was not responsible for the limiting of the flame.

In test 81 the length of flame was 215 feet beyond the end of the entry barrier. It seems probable that the dying away of the flame could not have been due solely to the barrier in this test.

In test 93 a five-shelf barrier in the air course in all probability failed to limit the flame, inasmuch as burned guncottons indicated that the flame reached 125 feet beyond the end of the barrier. The barrier shelves were broken up and some of them thrown out by as far as A 750, so that it is possible that the final stopping of the flame was due to the dust from the shelves.

In test 94 a similar five-shelf barrier in the air course evidently failed to stop the flame, since it extended 175 feet beyond the end of the barrier.

In test 355 two failures were obtained. The flame extended 190 feet beyond the barrier on the entry and 515 feet beyond the barrier in the air course. The entry barrier was not moved, but part of the air-course barrier was thrown down. The flame of this explosion traveled slowly and with low pressures. It is probable that the quantity of dust thrown into the air from the barrier was insufficient to quench the flame which passed under the shelves.

In test 406 the photographic paper showed flame 40 feet beyond the barrier, the matches being burned considerably farther than this. The flame traveled slowly in this test and the pressures were low. The barrier was not moved and lost only a little dust. The barrier probably failed, the explosion stopping for lack of fuel. The explosion was too weak to blow from the barrier enough dust to quench the flame.

In test 416 the barrier was near the pit mouth, the cannon being 230 feet in by, pointing directly at the barrier. There were no side openings between cannon and barrier to relieve the shock-wave pressure. The explosion traveled into the mine away from the barrier, developing high pressures and velocities. Flame also extended down to the barrier and 85 feet beyond to the pit mouth. The barrier was demolished and thrown out of the pit mouth. It is probable that the shock wave from the cannon, being confined and close to the barrier, may have thrown down the shelves. More than

a second elapsed between the firing of the cannon and the arrival of flame at the barrier. Meanwhile pressures of 50 to 60 pounds had been built up inby and these may have driven the flame through the wreckage of the barrier, at the same time carrying the débris out of the pit mouth.

In test 430, originated at the face of No. 2 butt, two failures were obtained in the air course, one inby and one outby No. 2 butt. The flame extended 100 feet and 170 feet beyond the barrier, respectively. The flame traveled very slowly, with pressures of only 1 pound per square inch. Only a small amount of dust was blown from the barrier, and was insufficient to quench the flame; the explosion passed under the barriers, dying out later for lack of fuel.

In test 432 the barrier failed on the entry, flame extending 115 feet beyond the shelves. This was another case in which a very weak explosion passed under the barrier without dislodging sufficient dust to extinguish the flame.

In test 466, originated at the face of No. 1 butt, the barrier at station A 675 failed. Here again a weak explosion passed under the barrier without being extinguished. The flame records in this test were confusing. A tin-foil was fused 75 feet beyond the barrier: matches and photographic paper gave records 20 feet beyond the barrier, but there were a number of unburned matches, unexposed photographic papers, and one unburned foil inby the barrier.

To summarize, the failures may be classed as follows: Seven resulted from explosions too weak to operate the barrier properly; four were due to an insufficient number of shelves; one was due to improper loading of the barrier; one was probably due to the barrier being thrown down too far in advance of the flame, and the cause of the two other failures is not readily determined.

DOUBTFUL CASES.

Four tests are listed in the table in which the operation of the barrier has been termed questionable. The reasons for this are discussed hereinafter.

In test 20 a wooden stopping had been erected inby the barrier. Both the stopping and the barrier were demolished. The flame did not pass the barrier. It is not known whether or not the stopping assisted in extinguishing the flame.

In test 61 a 10-shelf barrier was placed from stations A 1100 to A 1040. The flame extended 90 feet outby the barrier, as indicated by guncottons. There were no instruments in the air course. Whether the flame was extinguished by the barrier or died out for lack of fuel is an open question.

In test 74 the flame, as indicated by guncottons, passed 65 feet beyond a barrier located as in test 61. This barrier has been in place during some preceding tests in which the flame did not reach it. Some shale dust had been blown off, and the remainder became covered with soot. The action of the barrier in this test is questionable.

In test 277 the flame extended 50 feet beyond the barrier in the entry. It is possible that the flame was checked by the barrier, but the barrier was aided by the absence of coal dust outby. Under more severe conditions the barrier might have failed.

After the adoption of photographic paper recorders it sometimes happened that the guncottons, matches, tin-foils, and photographic papers did not give concordant results on the length of flame. The discrepancies can be readily ascribed to the widely different temperatures necessary to operate the devices and also to their relative location. In five tests (Nos. 346, 347, 356, 358, and 371), using seven barriers, the photographic paper record showed no flame beyond the barrier, whereas matches were burned from 40 to 155 feet beyond the barrier. These explosions were all violent, test 347 giving the highest pressure ever actually recorded in the mine. In determining the effectiveness of the barrier in these tests, in none of which coal-dust zones were outby the barrier, particular consideration was given to the reduction in pressure, the destruction of the barrier, and the location of fragments after the explosions. The decision was also influenced by the previous work of Clement and Scholl,* who found in laboratory experiments that with pulverized dust a temperature of 800° C or higher at the initiating source was necessary to cause flame to spread through a coal-dust cloud, the temperature depending upon the composition of the dust. For Pittsburgh coal dust the temperature was over 1,000° C. Such a temperature would produce enough light to affect photographic paper, and if no records are obtained on such paper outby the barrier in question it seems safe to assume that the temperature was below that necessary to cause propagation through coal dust. On the other hand, there may be instances where the flame does not fill the passage-way and the interposed dust cloud shuts off light.

TESTS OF HANGING SHELVES.

Hanging shelves can be classified as Taffanel shelves made more sensitive by suspension from hooks so placed that the shelves have some freedom to swing along the axis of the entry. If the swing extends beyond a certain point, the hooks slip from their supports

* Clement, J. K., and Scholl, L. A., Jr., The inflammability of Illinois coal dust: Bulletin 102, Bureau of Mines, p. 18.

and the shelf drops, dumping the dust. At the experimental mine the hooks were the hanger irons of the box barriers, described later, and they supported the shelf about 18 inches from the roof of the entry.

These shelves were very sensitive, a weak explosion throwing them down. Ignition tests in which the flame traveled 50 or 75 feet did not disturb them. Propagation tests traveling 150 to 200 feet usually threw down all the shelves, breaking some of them. The barrier was used in the air course only (at A 950 in explosions originated at the face of the entry, and at A 700 and A 900 in explosions originated in the rooms).

Results obtained with barriers of this type are given in Table 54. The barrier was used 49 times in 47 tests. Flame reached the barrier 26 times; the barrier stopped the flame 25 times and failed once; this failure, test 330, originated in No. 3 room, the barrier being at A 700. The explosion was strong and of long duration, pressure in No. 1 butt being above atmospheric for over five seconds. The resultant continued rush of gas past the location of the barrier probably first destroyed the barrier, carrying it out the air course, the flame afterwards having little obstruction.

Six shelves constituted the barrier which was uniformly successful until test 330. The failure in that test shows the necessity of a larger number of shelves of dust in a barrier unit. Ten at least would be advisable. The hanging-shelf type, on account of its greater sensitiveness, is probably an advance over the original Taffanel fixed shelf. However, it is open to the same objections: (1) The contamination of the dust by floating dust; and (2) in humid places, caking of the dust from moisture.

Barrier consisted in all tests of six shelves loaded with crushed roof (shale.)

Test No.	Date.	Position of barrier in mine (stations).	Did explosion reach barrier?	Flame.		Maximum pressure.				Remarks.	
				Approximate velocity on reaching the barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
						Station.	Pressure.	Station.	Pressure.		
				Feet per second.	Feet.		Lbs. per sq. in.		Lbs. per sq. in.		
247	1915. Nov. 19	A 947 to A 980	No.								Flame extended to A 1150. Shelves 1, 2, and 4 thrown down; others lost a little dust.
248	Nov. 22	do.	Yes	1,700	0	A 980	49	A 750	17	Yes	Barrier broken and scattered. Four Taffanel shelves used with hanging shelves.
249	Dec. 20	do.	Yes	750	0	do.	13	do.	4	Yes	Barrier broken and scattered.
250	Dec. 22	do.	Yes	620	15	do.	28	do.	6	Yes	Do.
251	Dec. 23	do.	Yes	225	0	do.	3	do.	1	Yes	Barrier thrown down, but not much broken.
252	Dec. 28	do.	Yes	140	0	do.	2	do.	1	Yes	Barrier thrown down.
253	Dec. 30	do.	Yes	400	0	do.	5	do.	1	Yes	Barrier broken and scattered.
256	1916. Jan. 3	do.	No.								Flame extended to A 1125. All shelves thrown down except Nos. 5 and 6.
257	Jan. 5	do.	No.								Flame extended to A 1075. All shelves thrown down.
258	Jan. 7	do.	No.								Flame extended to A 1100. All shelves thrown down.
270	Jan. 12	do.	Yes	400	0	A 980	2	A 750	1	Yes	All shelves thrown down, one broken.
271	Jan. 14	do.	No.								Flame extended to A 1200. All shelves thrown down except No. 6.
272	Jan. 17	do.	No.								Flame extended to A 1050. All shelves thrown down.
273	Jan. 19	do.	No.								Flame extended to A 1175. All shelves thrown down except No. 6.
274	Jan. 21	do.	Yes	1,600	0	A 950	19	A 750	9	Yes	Barrier broken and scattered.
275	Jan. 24	do.	Yes	1,000	0	do.	7	do.	2	Yes	Barrier broken.
276	Jan. 27	do.	No.								Flame extended to A 1225. Shelves 1, 4, and 5 thrown down.
277	Jan. 28	do.	Yes	390	0	A 950	3	A 750	1	Yes	Barrier broken and scattered.
299	Mar. 15	do.	Yes	450	0	do.	4	do.	1	Yes	All shelves thrown down. All broken except one.
300	Mar. 17	do.	Yes								Flame extended to A 975. All shelves thrown down except No. 1.
301 ^a	Mar. 20	do.	No.	1,500	0	A 950	32	A 750	14	Yes	Barrier broken and scattered along air course to station A 550.
302	Mar. 22	do.	Yes	1,200	0	do.	16	do.	6	Yes	Barrier broken and scattered along air course to station A 300.
303	Mar. 24	do.	No.								Flame extended to A 1000. All shelves thrown down except No. 2.
304	Mar. 27	do.	Yes	880	0	A 950	6	A 750	3	Yes	Barrier broken and scattered along air course to station A 600.
305	Mar. 29	do.	No.								Flame extended to A 1225. All shelves thrown down.

^a Tests illustrated by graphs: Test 262, figure 59; test 301, figure 3; test 330, figure 78.

TABLE 54.—Results obtained from tests of hanging-shelf barrier—Continued.

Test No.	Date.	Position of barrier in mine (stations).	Did explosion reach barrier?	Flame.		Maximum pressure.				Did barrier stop explosion?	Remarks.
				Approximate velocity on reaching the barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
						Station.	Pressure.	Station.	Pressure.		
306	1916. Mar. 31	A 947 to A 890....	Yes...	<i>Feet per second.</i> 125	<i>Feet.</i> 0	A 950....	<i>Lbs. per sq. in.</i> 2	A 750....	<i>Lbs. per sq. in.</i> 1	Yes...	Shelves 2 and 3 left up, with most of the dust on them; others thrown down. Flame extended to A 1150. All shelves down except Nos. 2 and 6, which lost one-half of dust.
307	Apr. 3	do.	No....								Flame extended to A 1125. Shelf 4 only one thrown down. Barrier broken and scattered along air course to station A 300.
308	Apr. 5	do.	No....							Yes...	Barrier broken and scattered along air course to station A 300.
309	Apr. 11	A 700 to A 650....	Yes...	90	0	A 750....	5			Yes...	All shelves thrown down except No. 1, which was hanging by one hook.
310	do.	A 947 to A 890....	No....								All shelves thrown down except Nos. 3 and 6; No. 3 had two hooks off.
310	Apr. 14	A 700 to A 650....	Yes...	120	10	A 750....	2			Yes...	Flame extended to 3R 125. Barrier not disturbed.
311	do.	A 947 to A 890....	No....								Flame extended to 1B 50. Barrier not disturbed.
312	Apr. 15	A 700 to A 650....	No....								Barrier broken and scattered.
313	Apr. 21	do.	No....							Yes...	All shelves thrown down. None broken.
314	Apr. 24	A 947 to A 890....	Yes...	1,600	0	A 950....	12	A 750....	7	Yes...	Barrier broken and scattered along air course to A 575.
315	May 3	do.	Yes...	200	0	do.	2	do.	1	Yes...	Barrier broken and scattered along air course to A 585.
319	May 3	do.	Yes...	1,700	0	do.	15	do.	7	Yes...	Barrier broken and scattered along air course to A 575.
320	May 6	do.	Yes...	700	0	do.	3	do.	1	Yes...	Shelves thrown down and broken.
321	May 8	do.	Yes...	700	0	do.	4	do.	1	Yes...	Explosion dying away. Shelves 1 to 3 left up, with part of dust gone; others down. 1.7 per cent gas in air current.
322	May 10	do.	Yes...	418	0	do.	4	do.	1	Yes...	Flame extended to A 1050. Shelves 4 and 5 only ones thrown down.
323	May 11	do.	Yes...	140	0	do.	2	do.	1	Yes...	Flame extended to A 1125. Shelf 4 only one thrown down.
324	May 13	do.	No....								one hook; others not affected.
325	May 16	do.	No....								Flame extended to 1B 50. Barrier thrown down and broken.
326	May 17	do.	No....								Flame extended to A 1175. Barrier not affected.
327	May 22	A 700 to A 650....	No....								Barrier broken and scattered to station A 700. 1.4 per cent gas in air current.
328	May 24	A 947 to A 890....	No....								Four Taffanel shelves used in addition. Barrier scattered to mouth of air course; barrier failed.
329	May 25	do.	Yes...	330	0	A 950....	3	A 750....	1	Yes...	
330	May 29	A 700 to A 650....	Yes...	290	375	1 B 50....	21		14	No...	

* Test illustrated, etc.

TYPES OF BARRIERS DEVELOPED BY THE BUREAU.

Taffanel shelves were first used in the experimental mine in an effort to localize certain explosions. They were almost uniformly successful with the moderate and violent explosions, but the flame of a light explosion, or what might be termed an inflammation, sometimes passed unchecked. A 10-shelf barrier in a passageway in the Clarence mine, France, that was traversed by an explosion in 1912 is thought to have failed in this way. Because of these failures the Bureau of Mines engineer tried to design other devices that would be more sensitive, having regard to the desirability of using the barriers with advantage not only in mines where rock dusting is employed but also where watering is done. This requirement called for inclosure of the rock dust, so that it might not become moist or wet, and thus be prevented from acting successfully.

Accordingly one of the authors devised certain types of barriers, some of which have been extensively tested with favorable results. A detailed description of these barriers and their mode of operation is given on page 567. Application for patents has been made by the designer, George S. Rice, for assignment to the Bureau of Mines, in order that any citizen of the United States may use the barriers freely.

Six types of barriers were designed, as follows:

1. Box barrier (consisting of six to eight individual boxes).
2. Concentrated barrier.
3. Rock-dust ventilating stopping.
4. Rock-dust-protected ventilating door.
5. Rock-dust-protected overcast.
6. Trough rock-dust barrier.

OBJECT OF THE DIFFERENT TYPES.

These types have been tested repeatedly at the experimental mine, and, in the final forms, were almost uniformly successful. The first two are for employment in every ventilating split near its entrance and elsewhere at intervals of one-quarter of a mile in all entries or headings in which coal dust is found. The placing of the third, fourth, and fifth types is implied by their names.

The underlying purpose of the operation of the barriers, in common with that of all rock-dust barriers, is to launch a mass (2 to 5 tons) of rock dust or other finely ground noninflammable dust into the air blast that always precedes a dust explosion. The air blast, termed by the English "the pioneering wave," by its eddying currents mixes the noninflammable dust with the coal dust. When the flame of the explosion reaches the dense cloud of dust, in which inert dust greatly

predominates, the latter extinguishes the flame by absorbing heat. Moreover, because of the large amount of rock dust used each particle of coal dust is probably surrounded by many particles of inert dust that form a screen between the flame and the coal dust. Sometimes the flame of the explosion is extinguished immediately, but a distance of 50 feet or thereabouts may be traversed before the inert dust borne by the explosion wave extinguishes all the flame.

The second requirement which is met by each of the bureau's designs is that a barrier shall be actuated by a slow-moving, nonviolent explosion. Slowness of movement, due to lessened inflammability of the dust encountered in the passage of the explosion through some entries, is more common, even in great disasters, than is continuous violence. In one Colorado disaster an explosion that started near the entrance, after showing much violence in a dusty old main haulage entry, ran inby along a connecting entry containing dust of less inflammability with so little violence in some stretches that it was difficult for an investigator to ascertain that an explosion had passed; even a shovel leaning against a rib was undisturbed. Farther inby the explosion again developed great violence.

The box barrier and the concentrated barrier are particularly sensitive to explosions. The concentrated barrier may also be actuated by additional tripping vanes, 100 feet or so in advance of the barrier itself, to insure operation by the slowest-moving explosion. Velocities of flame less than 100 feet per second have been recorded as compared with 20 times this speed in a fast, violent explosion and 30 or more times this speed in what may be termed a "detonating" explosion.

When the explosions are violent, giving pressures of, say, more than 30 pounds per square inch, any one of the barriers will be torn to pieces, and the rock dust, being instantly mixed by the fast moving blast, will quench the flame.

The third requirement to be met is that, should the device be operated by an advance air wave far ahead of the flame of the explosion or by the flame coming from another circuit of the explosion, some rock dust shall be retained on certain parts of the barrier in addition to what may be scattered along the passageway. To insure dust being retained, shelves are hung from the roof with chains, or, in the rock-dust-protected ventilation stopping, open shelves are held by posts.

The fourth requirement met in the designs was that the rock-dust containers should be so inclosed that the rock dust would not become wet in mines where humidifying or watering is practiced or be contaminated by floating coal dust.

The fifth feature, applying only to the box barrier, the rock-dust-protected door, and one of the two concentrated barriers, was to

provide that accidental tripping would not seriously injure anyone passing. The requirement was met by limiting the fall of the heavy parts by chains hung from the roof or overhead timbers. The other devices do not need to meet this requirement because of their position or construction.

Rock dust in overhead places, extending across the passageway, has been found far more effective than dust placed on side shelves, because the dust falls across the path of the explosion.

KIND OF DUST TO USE IN BARRIERS.

Dust for barriers should be as free from combustible matter as possible. Moreover, finely ground dust is better adapted for making a dust cloud and being borne along by the current with the coal dust. The specific gravity, or weight, of the particles of inert dust in comparison with equal-sized particles of coal dust seems to be less important than it is for dust used in continuous treatment along the roadway. In the barriers the dust falls from overhead and does not have to be raised into suspension. The dusts tried at the experimental mine in the barriers are shale dust and limestone dust, but doubtless many other fine inert or incombustible dusts would be equally effective.

TESTS OF BOX BARRIERS.

Four types of so-called box barriers were tested, designated as follows: Box A, box B-1, box B-2, and box C.

CONSTRUCTION OF TYPE A BOX BARRIER.

A box of the first form of barrier was an open top box of the approximate overall dimensions of 8 feet long by 10 inches high by 22 inches wide. Its capacity was about 10 cubic feet. Attached to the under side of the box at each end was a 3-inch by 4-inch strip, to the lower side of which was fastened a bar with eyes at each end, extending a little beyond the sides of the box. The box was supported near the roof by suspension bars about 16 to 18 inches long, with hooks on each end. The lower hooks were inserted in the eyes of the under bars, while the upper ones rested over bolts extending out from the ribs near the roof. The suspension bar arrangement permitted the box to swing when acted upon by the advance wave of the explosion and caused the side of the box, or the cleats nailed to it, to force the hooks on the side away from the advancing explosion from their support, resulting in the dumping of the contents of the box into the entry. The hooks on the upper end of the suspension bars were made at an angle of 95 degrees to the bar. Their adjustment was such that usually only a slight

pressure against the suspension bar would cause the hook to slide from the support.

Plate XV, *B* (see p. 428), shows the appearance of a four-box barrier of this type in the experimental mine. In operating mines the top should be covered by a waterproof curtain.

PRELIMINARY TESTS OF TYPE A BOX BARRIER.

Beginning with test 84, a single box of this type was installed in the mine in the air course at A 1140 and later near A 1100 in order to get some preliminary data as to the way it would operate in the explosions. Its use in a number of tests showed that a dust box of that type could be operated successfully even by very low-pressure waves. Accordingly in test 101, a pure coal-dust test with a 600-foot zone in the parallel entry, a barrier of four boxes was installed at A 1240-1200. The boxes operated and were broken to pieces by the explosion, the dust being scattered for about 100 feet outby the barrier position. The guncottons were burned for 250 feet outby, so presumably the barrier failed.

In the two following tests similar barriers were installed at the same point, but failures resulted in each case. It is believed the result was due to the position of the barrier—just outby the 1250 cut-through—and the consequent uneven distribution of pressure from the pressure wave against the side of the box, owing to the wave front taking a curved path around the corner of the cut-through. The boxes in many instances were thrown down only on the side away from the corner and in others were thrown alongside the near rib. This manner of dumping prevented the dust being dumped into the air in an evenly distributed manner. The barriers were later installed at points farther from the cross-cut, so that the pressure waves would strike the barrier more evenly along its full width.

LATER TESTS ON THE TYPE A BOX BARRIER.

A detailed description of this barrier and its mode of operation is given in the appendix.

Twenty-three barriers of this type were installed at points from 350 to 550 feet from the origin of the explosion and operated with the following results:

In twelve cases the explosion was stopped by the barrier; in four cases the explosion did not reach the barrier, but the boxes dumped; in seven cases the barrier failed to stop the explosion. Only four boxes were used to a barrier, which is too few; six or eight should be used. Hence the failure here is not regarded as condemnatory.

Table 55 accompanying indicates the more important points in connection with these tests of the barriers.

TABLE 55.—Results obtained from tests of type A box barrier

[Barrier consisted of four boxes in all tests.]

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Did barrier stop explosion?	Remarks.
					Position in mine (stations).	Kind of dust used.	Point reached at time of operation box 1 to box 1 (station), barrier.	Time from operation of box 1 to arrival at barrier.	Approximate velocity on barrier.	Length beyond barrier.	Inby barrier.				Outby barrier.
		Station.	Pressure.								Station.	Pressure.		
101	1914, Mar. 25	A 1240 to A 1200...	Limestone	Yes									No...	Barrier failed; too near corner.
102	Mar. 31	do.	Shale...	Yes									No...	Barrier failed; too near corner. Dust left in a heap.
103	Apr. 13	do.	do.	Yes									No...	Barrier failed; too near corner. Dust well distributed.
104	Apr. 16	E 947 to E 917...	Limestone	Yes	1.17	750	65	E 1150	8	E 750	3	Yes...	Yes...	Dust scattered to E 775. Box 4 operated 1.10 seconds before flame.
105	Apr. 18	A 800 to A 770...	Shale...	Yes	.16	600	0	A 950	19			Yes...	Yes...	Barrier demolished.
106	Apr. 21	E 947 to E 917...	Limestone	No...										Flame extended to E 1080. Barrier thrown down and broken.
107	Apr. 23	do.	Shale...	Yes	.83	500	40	E 950	5	E 750	4	Yes...	Yes...	Barrier scattered to E 575. Box 4 operated 0.83 seconds before flame.
107	do.	A 947 to A 917...	do.	Yes	.87	150	65	A 950	8			Yes...	Yes...	Barrier demolished.
108	Apr. 27	do.	do.	Yes			0	A 950	0			Yes...	Yes...	Barrier thrown down and broken.
108	Apr. 29	do.	do.	Yes	.83	800	65	A 950	14			Yes...	Yes...	Barrier demolished and scattered along air course to A 350.
110	May 2	E 780 to E 760...	do.	Yes	3.34	60	0					Yes...	Yes...	Barrier demolished and scattered along entry to E 550.
110	do.	A 947 to A 917...	do.	Yes			65					Yes...	Yes...	Barrier demolished and scattered along air course to A 650.
111A	May 5	E 780 to E 760...	do.	No...										Flame extended to E 1250. Barrier not disturbed.
111A	do.	A 947 to A 917...	do.	No...										Flame extended to A 1220. Boxes 3 and 4 thrown down.
111B	do.	E 780 to E 760...	do.	No...										Flame extended to E 975. Boxes thrown down.

* Tests illustrated by graphs: Test 105, figure 10; test 109, figure 15; test 113, figure 16; test 115, figure 11.

TABLE 55.—*Results obtained from tests of type A box barrier—Continued.*

[Barrier consisted of four boxes in all tests.]

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.		
					Position in mine (stations).	Kind of dust used.	Point reached at time of operation of box 1 at (station) barrier.	Time from operation of box 1 to arrival at barrier.	AP- proximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.			Outby barrier.	
		Station.	Pressure.								Station.	Pressure.		Station.	Pressure.
111B	do.	A 947 to A 917.	do.	Yes										Yes	Boxes remaining from test 111A thrown down; fragments scattered to A 575.
112	May 8	do.	do.	Yes	E 1250	1.40	320	65						Yes	Bar jar thrown down.
112a	May 9	do.	do.	Yes	C. T. 30	.53	880	65	A 960	32	A 750	9		Yes	Barrier demolished and scattered to A 401.
114	May 12	A 744 to A 714.	do.	Yes	1B 60	.60	400	140	A 750	4	A 550	3		No	Barrier demolished and scattered to A 200.
115a	May 20	E 947 to E 917.	Limestone	Yes	E 1165	.19	1,800	450	E 960	36	E 750	36		No	Barrier demolished and scattered to E 625.
115	do.	A 947 to A 917.	do.	Yes	A 1240	.30	1,500	165	A 950	80				No	Barrier demolished and scattered to pit mouth.
116	May 25	E 947 to E 917.	do.	Yes	E 1270	.31	2,000	565	E 950	21	E 750	30		No	Barrier demolished.
116	do.	A 947 to A 917.	do.	Yes	E 1280			65	A 950	25				Yes	Barrier demolished and scattered to A 150.

* Tests illustrated by graphs. Test 105, figure 10; test 109, figure 15; test 113, figure 16; test 115, figure 11.

The tests on these barriers were made without the installation of fine coal-dust zones beyond them; on this account the tests of this form of barrier are not as conclusive as they would be otherwise. In all tests in which the barrier is credited with stopping the explosion the flame, as indicated by matches, did not extend over 65 feet beyond the barrier. In most cases the boxes dumped in from 0.5 to 1.5 seconds, as given by the record of a break in an electric circuit when the box falls, ahead of the burning of the tin foil at the near-by station. The dumping would result in the formation, in advance of the arrival of the flame, of dense clouds of rock dust in the air and of large heaps of dust on the floor, which might be raised later by the main explosion wave. The rock dust clouds would probably extend a considerable distance beyond the barrier by the time the flame reached that position; thus the flame might extend some distance beyond the original position of the barrier and yet the barrier must be responsible for its quenching.

FAILURES.

In test 114 the boxes dumped 0.6 second before the foil was burned. The considerable extension of the flame—140 feet beyond the barrier—seems to indicate that the action of the barrier was not successful.

In test 115 the coal dust was placed entirely on cross shelves. The resulting explosion was exceedingly rapid, probably more rapid than any explosion which might occur in an operating mine unless there was a considerable percentage of gas in the air current. The flame reached the barriers before there had been sufficient time for effective cloud formation, and the flame passed by their location. Since the explosive dust on the cross shelves was so high, it is also possible that the first flame may have been very close to the roof and therefore passed over the boxes.

In test 116 the explosion was slow in starting, not reaching E 1150 and A 1150 until over two seconds after ignition. The boxes had operated by 0.6 second after ignition in the air course and 1.3 seconds in the entry. The explosion was not stopped in the entry; this may have been due to the fact that the dust was on cross shelves, so that the flame traveled near the roof and passed over the overthrown boxes.

In all of the tests the capacity of each of the boxes of the four-box barrier was 40 cubic feet, or about the same as in a 10-shelf Taffanel barrier. In order that the same ratio of dust to cross section of entry would prevail for boxes as would be true for a 15-shelf Taffanel barrier, six boxes should be used. It is probable that the increased quantity of dust in two additional boxes might have changed failure to success in the last three tests.

The number of failures with this preliminary type led to important modifications in the succeeding types.

TESTS OF BOX BARRIERS, TYPE B.

In the B-type box barrier the bottom boards of the box were not rigidly connected to the balance of the box, but rested on strips beneath them which were nailed to the box frame. Plate XVI shows the arrangement of bottom strips and boards above. The boards have yokes of chain at each end attached to hooks in the roof. The chains ordinarily have 3 to 4 inches of slack. When the box dumps, the chains hold the bottom boards up, thus serving two purposes: First, the mass of dust in the box is broken up as it falls, and, second, a portion of the dust is retained on the shelves near the roof. The first effect enumerated prevents the contents of the box from being thrown to the floor in a more or less concentrated heap, which is undesirable as giving only a small surface area for the air current to act on; the second overcomes the condition which may have prevailed in the entry in test 116 and others; that is, the box operated considerably ahead of the flame, and the dust cloud to a great extent may have been blown out by; when the flame arrived, the only dust present to check it was on the floor and consequently the flame passed over it. When the shelves are held up some dust is retained on them in the less violent explosions, and when the flame arrives can be blown off the suspended shelves by the main explosion wave, quenching the flame. Plate XVII, A, shows such shelves suspended after a light explosion test. Plate XVII, B, shows the effect of a strong explosion on the type B box barrier.

Similar arrangement of bottom boards was used in both B types, the only difference in barriers B-1 and B-2 being in the character of the suspension bar; in the B-1 type the upper end of the suspension bar was a hook similar to that of Plate XV, B, while in B-2 it was an eye which fitted over a hook, as shown in Plate XVI. The former arrangement was believed to be too easily dislodged by an accidental blow or jarring, whereas in the latter type the weight of the box helped to hold the eyes on the hooks, which faced in opposite directions away from the box. Neither of these types is recommended, type C being preferred.

TESTS OF TYPE B-1 BARRIER.

The tests of type B-1 barrier, given in Table 56, consist of all those in which the flame reached or passed the barrier, and some cases in which the flame did not reach the barrier, but the barrier operated notwithstanding. In 17 tests of the B-1 type of barrier the flame



BARRIER OF SIX BOXES IN MINE ENTRY. ROCK DUST IS PROTECTED BY OILCLOTH COVERS. THE WIRING AT THE UPPER RIGHT-HAND CORNER IS NOT PART OF THE BARRIER.



A. VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON BOX BARRIER.



B. VIEW SHOWING EFFECT OF STRONG EXPLOSION ON BOX BARRIER.

reached the barrier in 12. In 10 out of these 12 trials the barrier operated successfully. The maximum pressures in these tests were not very great; in only two (tests 126 and 145) did the pressure—21 pounds—exceed 10 pounds. The velocity of the explosions was consequently not very great. The records of the time of fall of the barriers showed that they usually operated 0.3 second or more ahead of the burning of the last tin-foil in by the barrier. In very rapid explosions the interval was shorter, and in these cases there was a greater possibility of failure due to the barrier not operating soon enough. If the interval was very great, there might have been a lapse of time sufficient for the dust cloud to settle or be partly blown away, and then greater responsibility was placed on the action of the suspended bottom boards in retaining part of the dust.

TABLE 56.—Results of tests of Type B box barrier.

TESTS OF TYPE B-1.

Test No.	Date.	Barrier.		Kind of dust.	Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.	
		Position in entry or air course (stations).	Num-ber of boxes.			Point reached at time of opera-tion of boxes.	Time from opera-tion of box to arrival of flame.	Ap-proxi-mate velocity on reach-ing barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			Did barrier stop explosion?
										Box No.	Loca-tion of flame (sta-tion).	Sec-onds.	Ft. per sec.			Lbs. per sq. in.	Sta-tion.	Pres-sure.	Lbs. per sq. in.	Sta-tion.	Pres-sure.
117	1914 May 27	E 947 to E 917...	4	Limestone	Yes...	1	E 1230	0.63	450	E 950	E 750	4	Yes...	Boxes broken and scattered to E 50.	
117	do.....	A 947 to A 917...	4	do	Yes...	1	C. T. 35	1.52	90	A 950	10	4	Yes...	Boxes broken and scattered to A 450.	
119	June 2	E 947 to E 917...	4	do	Yes...	1	E 1090	.39	420	E 950	8	4	Yes...	Boxes broken and scattered to E 650.	
119	do.....	A 947 to A 917...	4	do	Yes...	1	A 1180	.87	300	A 950	7	4	Yes...	Boxes broken and scattered to A 550.	
126	June 22	do.....	4	Shale	Yes...	1	A 1170	.40	400	A 950	21	4	Yes...	Boxes broken and scattered to A 300.	
126	June 25	E 947 to E 917...	4	do	No...									Flame extended to E 975. Boxes not disturbed.	
126	do.....	A 947 to A 917...	4	do	No...									Flame extended to A 1075. Boxes not disturbed.	
132	June 27	E 947 to E 917...	4	do	Yes...	1	E 1220	.60	1,000	E 950	7	E 750	4	Yes...	Boxes broken and scattered to E 775.
132	do.....	A 947 to A 917...	4	do	Yes...	1	C. T. 30	.87	325	A 950	9	4	Yes...	Boxes broken and scattered to A 550.	
133	June 30	E 947 to E 917...	4	do	No...									Flame extended to E 1200. Box 4 operated.	
133	do.....	A 947 to A 917...	4	do	No...									No flame in air course. Boxes undisturbed.	
136	July 7	E 927 to E 917...	2	Limestone.	Yes...	1	E 1000	.13	400	E 950	0	E 750	5	No...	Two boxes not sufficient to stop explosion.
136	do.....	A 927 to A 917...	2	do	Yes...				500	A 950	0	A 950	0	Yes...	Boxes broken and scattered to A 800.

143	Oct. 30	E 947 to E 917...	4	do...	Yes...	1	E 1040	.34	250	895	E 950	2	E 750	9	No...	Coal-dust zone (E 915 to E 800) ignited. Boxes failed.
143	do...	A 947 to A 917...	4	do...	Yes...	1	A 1040	.30	170	0	A 950	7	A 750	2	Yes...	Boxes broken. Flame extended to A 1075. Box 4 thrown off 1 hook.
144	Nov. 4	do...	4	do...	No...											Boxes broken and scattered to A 450.
145	Nov. 9	do...	4	do...	Yes...	1	A 1170	.30	1,000	0	A 950	21	A 750	0	Yes...	

Tests of Type B-2.

120	1914 June 11	A 700 to A 650...	6	Shale...	Yes...	1	A 750	0.22	200	0	A 750	3			Yes...	Boxes thrown down. Coal-dust zone outby barrier not ignited. Flame extended to A 800. Boxes thrown down. All boxes thrown down. All shelves left hanging. Dust was down.
141	Oct. 9	do...	6	Limestone...	No...											
147	Dec. 3	E 947 to E 917...	4	Shale...	Yes...	1	A 1075	.20	800	90	E 950	7	E 750	5	No...	
147	do...	A 947 to A 917...	4	do...	Yes...	1	A 1060	.44	270	0	A 950	4	A 750	2	Yes...	All boxes thrown down. All shelves left hanging. Three shelves broken.
148 ^a	Dec. 4	A 700 to A 650...	6	Limestone...	No...											
148	do...	A 917 to A 947...	4	do...	No...											All boxes down. Two shelves broken.
149	Dec. 8	E 947 to E 907...	6	do...	Yes...	1	E 1090	.45	350	300	E 950	7	E 750	3	No...	Coal-dust zone outby ignited.
149	do...	A 947 to A 907...	6	do...	Yes...	1	A 1165	.55	470	0	A 950	4	A 750	1	Yes...	All boxes down. Four shelves broken.
150	Dec. 11	E 947 to E 907...	6	Shale...	Yes...	1	A 1060	.59	170	25	E 950	4	E 750	2	Yes...	All boxes down. Coal-dust outby barrier not ignited.
150	do...	A 947 to A 907...	6	do...	Yes...	1	A 1135	.73	350	0	A 950	5	A 750	2	Yes...	Do.
151	Dec. 14	E 947 to E 907...	6	Limestone...	Yes...	1	A 1045	.95	100	900			E 750	1	No...	All boxes down. Coal dust outby barrier ignited.
151	do...	A 947 to A 907...	6	do...	No...											By barrier ignited.
152	Dec. 18	E 947 to E 377...	8	do...	Yes...	1	E 1185	.50	600	0	E 950	19	E 750	5	Yes...	Boxes 3 and 4 thrown down. All boxes thrown down. Eight shelves broken. Elements scattered to station E 450.
						2	E 1175	.48								
						3	E 1175	.45								
						4	E 1185	.49								
						5	E 1185	.49								
						6	E 1160	.41								
						1	A 1150	.44								
152	do...	A 947 to A 800...	6	Shale...	Yes...	1			530	0	A 950	8	A 750	2	Yes...	Boxes thrown down. Eight shelves broken.
153	Dec. 22	E 947 to E 907...	6	do...	Yes...					0	E 950	2	E 750	1		Flame extended to E 925 (indicated by match). Fall at E 950 not used. No boxes down. Flame extended to A 1000. Box 4 down.
153	do...	A 947 to A 917...	4	do...	No...											

^a Test 148 illustrated by graph, figure 77.

TABLE 56.—Results of tests of type B box carrier—Continued.

TESTS OF TYPE B-1—Continued.

Test No.	Date.	Barrier.			Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.	
		Position in entry or air course (stations).	Num-ber of boxes.	Kind of dust.		Point reached at time of opera-tion of boxes.	Time from opera-tion of box to arrival of flame.	Ap-proxi-mate ve-locity on reach-ing barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
										Sta-tion.	Pres-sure.	Sta-tion.	Pres-sure.		
					Box No.	Loca-tion of flame (sta-tion).	Sec-onde.	Ft. per sec.		Lbs. per sq. in.		Lbs. per sq. in.			
154	1914.													Flame extended to E 1150. Box 1 off one hook.	
154	Dec. 28	E 947 to E 897...	6	Shale...	No...									Flame extended to A 1150. Boxes 1 and 4 thrown down.	
155	..do..	A 947 to A 917...	4	..do..	No...									Flame extended to E 1050. Box 1 off one hook.	
155	Dec. 31	E 947 to E 897...	6	..do..	No...									Flame extended to E 1075. All boxes thrown down.	
155	..do..	A 947 to A 917...	4	..do..	No...										
156	1915.													Box 4 down.	
156	Jan. 5	E 947 to E 897...	6	..do..	Yes...	4	E 1240	7.08	20	0		E 750	1	Yes...	
156	..do..	A 947 to A 917...	4	..do..	Yes...	1	E 1250	4.44	90	0		A 750	1	Yes...	
157	Jan. 8	..do..	4	..do..	No...	4	G. T. 25	4.13						Flame extended to A 1150. Box 4 operated.	
158	Jan. 12	..do..	4	..do..	No...									Flame extended to A 1150. All boxes down except No. 2; 0.9 per cent gas in air current.	
159	Jan. 15	..do..	4	..do..	No...									Flame extended to A 975. All boxes operated; 3.0 per cent gas in air current.	
161	Jan. 21	..do..	4	..do..	Yes...	1	A 1160	.10	3,800	215	A 900	85+	A 750	26	No....
163	Jan. 25	..do..	4	..do..	No...										Barrier demolished and scattered in air current; 3.4 per cent gas in pit mouth; 3.4 per cent gas in air current.
															Flame extended to A 1200. Box 4 operated; 1.1 per cent gas in air current.

164	Jan. 26	do.	4	do.	Yes...	1	C. T. 30 A 1245	1.00 .89	500	0	A 950	5	A 750	0	Yes...	All boxes thrown down. Four shelves broken. 2.5 per cent gas in air current. Flame extended to A 1050. Box 4 operated. 2.8 per cent gas in air current. Boxes 1 and 4 operated. Box 1 fell after flame passed. 3.2 per cent gas in air current. Flame extended to 1250. Box 4 down on west side. 1.3 per cent gas in air current. Flame extended to A 1000. Box 4 operated. 1.1 per cent gas in air current. Barrier demolished and scattered to A 550.
168	Feb. 1	do.	4	do.	No...											
171	Feb. 5	do.	4	do.	Yes...	1	A 725	-3.72	50	340	A 950	0	A 750	0	No...	Boxes 1 and 4 operated. Box 1 fell after flame passed. 3.2 per cent gas in air current. Flame extended to 1250. Box 4 down on west side. 1.3 per cent gas in air current. Flame extended to A 1000. Box 4 operated. 1.1 per cent gas in air current. Barrier demolished and scattered to A 550.
173	Feb. 9	do.	4	do.	No...											
174	do.	do.	4	do.	No...											
175	Feb. 12	do.	4	do.	Yes...	1	A 1160	.28	1,250	0	A 950	16	A 750	4	Yes...	All boxes thrown down. Flame extended to A 1125. All boxes thrown down except No. 3.
195	Mar. 29	do.	4	do.	Yes...	1	A 1175	.46	1,000	0	A 950	10	A 750	4	Yes...	Barrier demolished and scattered to A 550.
196	Apr. 2	do.	4	do.	No...											
197	Apr. 6	do.	4	do.	Yes...	1	C. T. 15	.95	700	0	A 950	5	A 750	0	Yes...	Barrier demolished and scattered to A 550.
201	Apr. 12	do.	4	do.	Yes...	1	A 1170	.17	1,000	65	A 950	33+	A 750	19	No...	Barrier demolished and scattered.
202	Apr. 17	do.	4	do.	Yes...	1	A 1185	.36	1,300	0	A 950	14	A 750	4	Yes...	Barrier demolished and scattered to A 300.
204	Apr. 21	do.	4	do.	Yes...	1	A 1075	.26	600	115	A 950	6	A 750	0	No...	Barrier demolished. 1.0 per cent gas in air current.

The two failures were in tests 136 and 143. In test 136 there were only two boxes in position, so that a failure under such conditions was not surprising. In test 143 a four-box barrier failed in a relatively slow explosion, a coal-dust zone outby being ignited. This indicates the desirability of a greater number of boxes being used.

TESTS OF TYPE B-2 BARRIER.

Thirty-nine trials of the B-2 type of box barrier are given in Table 56. These include all tests in which flame reached the barrier. In 17 of these 39 trials flame did not reach the barrier, but one or more of the boxes was dumped. The barrier failed to stop the explosion in 7 of the 22 tests in which the flame reached the barrier. Two of the failures were with six-box barriers, the others being with four boxes. In one test (No. 153) the flame extended 25 feet into the barrier, but as the latter did not operate it was in no way responsible for the result. Of the 14 cases of successful operation, 8 were made with pure coal-dust zones outby, so that if the flame had not been quenched it would have ignited the coal dust. The range of pressure inby the barrier in the tests with successful results was from 3 to 19 pounds per square inch; in the tests resulting in barrier failures the pressure was from 0 to 7 pounds in five cases. In the two remaining cases it was more than 33 and 55 pounds, respectively. In most of the tests in which the flame reached the barrier from half to all of the shelves were broken by the explosion.

In test 147 a four-box barrier failed; the failure probably was due to the dust having become damp. In test 149 a six-box barrier failed; the only probable explanation of this failure is that the floor was very wet and when the dust fell not much rebounded or was blown into the air current.

In test 151 the explosion was very weak; the No. 1 box record indicated dumping almost a second before the tin foil burned. It may be that the other boxes failed to operate quickly enough or that the very wet floor may have prevented an effective rebound of the dust. Only two of the barrier shelves were broken.

In test 161 there was 3.5 per cent of gas in the air current; the resulting explosion was very rapid and the barrier evidently did not operate quickly enough to quench the flame. Only four boxes were used, which is less than the number recommended. In test 171 a four-box barrier failed to stop a light-pressure, slow-moving explosion. A four-box barrier also failed in a rapid-moving explosion in test 201, and a slow explosion in test 204.

The results of the tests indicated that a four-box barrier is not sure enough in action to be recommended. It is believed that a six-box barrier will usually stop an explosion. Because there may not



A. VIEW OF BOX BARRIER, MODEL C, AFTER DUMPING.



B. TYPE B CONCENTRATED BARRIER IN POSITION IN MINE ENTRY. :



A. V-TROUGH BARRIER IN POSITION IN EXPERIMENTAL MINE.



B. TROUGH BARRIER INSTALLED IN MINE ENTRY, SHOWING NOTCHED SUPPORTING BLOCKS AND SPRAGS.

be on the shelves enough dust near the roof to quench a flame arriving considerably later than the operation of the barrier, type C, a modification of the B type was made to retain more of the dust near the roof.

TESTS OF TYPE C BOX BARRIER.

A detailed description of the type C barrier and its mode of operation is given on page 567. This type of box barrier differed from the B type in that two grids were added above the bottom boards, and when the barrier operated, these, as well as the bottom boards, were suspended from the roof by the same chains.

The chain lengths between grids and roof and grids and shelves were so arranged that no two grids or shelves were on the same level. This arrangement retained some dust quite near the roof and exposed a greater dust-pile surface to the air current. Plate XVIII, A, shows the relative position of such grids and the shelves after a box of the type C form had been operated.

In developing the arrangement of the type C barrier a large number of tests were made, 54 of which are given in Table 57. These tests comprise those in which the flame reached the barrier or the barrier operated to some extent. In 35 of the tests the flame reached the barrier, and of this number of trials of the barrier 25 were successful, 9 were unsuccessful, and 1, in which the barrier did not operate but in which the flame died away, was considered doubtful.

In six of the nine failures gas (0.8 to 3.4 per cent) had been put into the air current. It also appears significant that of the 13 tests of the group in which gas was present, six should be failures. From this evidence it seems that the presence of gas greatly increases the liability of failure of a barrier unsupported by other methods.

TABLE 57.—Results of tests of type C box barrier.

[Barrier loaded with crushed roof shale in all tests.]

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Did barrier stop explosion?	Remarks.	
		Position in entry or air course (stations).	Number of boxes used.		Point reached at time of operation of boxes.	Time from operation of box to arrival of flame.	Ap- proximate velocity of reaching barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.				
									Box No.	Location of flame.	Sec- onds.	Ft. per sec.			Station.	Pres- sure.	Station.	Pres- sure.
157	1915. Jan. 8	E 947 to E 917	4	No...											Flame extended to E 1125. Box 2 operated. Flame extended to E 1050. Box 2 operated. 0.9 per cent gas in air current. Box 2 operated. Box 4 off one hook; boxes 1 and 3 not operated. 3 per cent gas in air current. Barrier demolished and scattered. Opera- tion too slow; 3.4 per cent gas in air current. Boxes operated. Most of grids and shelves broken; 2.5 per cent gas in air current.
158	Jan. 12	do.	4	No...											
159	Jan. 15	do.	4	Yes...	2	E 1230	3.59	110	90	E 950	1	E 750	1	No...	
161	Jan. 21	do.	4	Yes...	1	E 1150	.10	6,000	900			E 750	65	No...	
164	Jan. 26	E 947 to E 897	6	Yes...	2	E 1090	.08	300	0			E 750	4	Yes...	
168	Feb. 1	do.	6	Yes...	2	E 1215	.89		0			E 750	0		Flame extended to E 950 (indicated by matches). E 950 and E 1050 falls not fused. Barrier undisturbed. 2.8 per cent gas in air current. Flame extended to E 1225. Box 3 down on one end. 2.8 per cent gas in air current. Boxes 3 and 5 operated. Boxes 1 and 4 partly operated. 3.2 per cent gas in air current. Flame extended to E 1200. Box 1 off one hook. 1.3 per cent gas in air current. Box 1 operated; others did not. 1.1 per cent gas in air current. All boxes operated. Barrier badly broken.
170	Feb. 5	do.	6	No...											
171	do.	do.	6	Yes...	1	E 1280	5.13	200	20	E 950	1	E 750	0	Yes...	
173	Feb. 9	do.	6	No...											
174	do.	do.	6	Yes...	1	E 1260	2.43	150	45	E 950	2	E 750	0	No...	
176	Feb. 12	do.	6	Yes...	1	E 1130	.63	410	45	E 950	12	E 750	4	Yes...	
178	Feb. 17	do.	6	Yes...	4	E 1180	.36	1,400	170	E 950	33	E 750	14	No...	All boxes operated. Most of grids and shelves smashed. 2.3 per cent gas in air current.

178	...do....	A 947 to A 917...	4	Yes...	1	A 1225	.29	1,600	0	A 950	23	A 750	5	Yes...	Barrier demolished and scattered. 2.3 per cent gas in air current.
182	Feb. 24	E 947 to E 897...	6	Yes...	1	E 1220	1.20	850	220	E 950	15	E 750	9	No...	All boxes down. Most of grids and shelves broken. 3 per cent gas in air current.
182	...do....	A 947 to A 917...	4	Yes...	1	A 1250	.81	500	0	A 950	5	A 750	2	Yes...	Barrier demolished and scattered to station A 500. 3 per cent gas in air current.
183	Mar. 1	...do....	4	No...											Flame extended to station A 1150. Box 1 operated; boxes 2 and 4 off one hook; others did not operate.
184	Mar. 3	E 947 to E 897...	6	Yes...	1	E 1260	2.93	80	0	E 950	2	E 750	0	Yes...	Box 4 operated; box 1 off one hook; others did not operate.
184	...do....	A 947 to A 917...	4	Yes...					0	A 950	2	A 750	0	Yes...	Boxes 3 and 4 operated; Boxes 1 and 2 did not.
185	Mar. 5	E 947 to E 897...	6	No...											Flame extended to E 1025. Boxes 1 and 3 came off hooks but caught on shelves.
185	...do....	A 947 to A 917...	4	No...											Flame extended to A 1075. Boxes 1 and 4 operated; box 3 off one hook; box 2 off two hooks.
186	Mar. 8	E 947 to E 897...	6	No...											Flame extended to E 1175. Boxes 1 and 2 operated.
186	...do....	A 947 to A 917...	4	No...											Flame extended to A 1250. Boxes 1 and 4 operated; box 3 off one hook.
187	Mar. 10	E 947 to E 897...	6	No...											Flame extended to E 1175. Box 1 off one hook; box 2 off two hooks.
187	...do....	A 947 to A 917...	4	No...											Flame extended to A 1200. Boxes 1, 3, and 4 operated; box 2 off two hooks.
188	Mar. 12	E 947 to E 897...	6	Yes...	1	E 1230	.91	500	0	E 950	19	E 750	7	Yes...	All boxes operated. Most of grids and shelves broken.
188	...do....	A 947 to A 917...	4	Yes...											Barrier demolished and scattered to A 400.
188	Mar. 16	E 947 to E 897...	6	Yes...	1	C, T, 20	.75	700	0	A 950	11	A 750	3	Yes...	Barrier demolished and scattered.
188	...do....	A 947 to A 917...	4	Yes...	1	E 1065	.03	2,000	170	E 950	23	E 750	26	No...	Barrier demolished and scattered to A 250.
189	Mar. 18	E 947 to A 917...	4	Yes...	1	A 1180	.18	2,500	15	A 950	68	E 750	67	Yes...	Boxes operated. Many of the grids and shelves were broken.
190	Mar. 18	E 947 to E 897...	6	Yes...	1	E 1220	.53	800	45				10	No...	Barrier demolished and scattered to A 250.
190	...do....	A 947 to A 917...	4	Yes...	1	A 1235	.41	1,500	0	A 950	19	A 750	17	Yes...	Barrier demolished and scattered to A 770.
194	Mar. 24	...do....	4	Yes...	1	A 1170	.18	2,000	40	A 950	30	A 750	30	Yes...	1 per cent gas in air current.
220	Oct. 4	A 947 to A 880...	6	No...											Flame extended to A 1225. Box 4 off one hook.
225	Oct. 11	...do....	6	Yes...					0	A 950	5	A 750	0	Yes...	All boxes operated except No. 3. Most of grids broken.
226	Oct. 14	...do....	6	No...											Flame extended to A 1100. All boxes operated.
237	Oct. 18	...do....	6	Yes...					0	A 950	75	A 750	27	Yes...	Barrier demolished and scattered to A 350.
242	Nov. 9	...do....	6	Yes...	1	A 1100	.25	1,000	0				3	Yes...	Boxes operated. Only three grids and shelves left up.
269	Jan. 10	...do....	6	Yes...	1	A 1240	1.23	400	0	A 950	3	A 750	1	Yes...	All boxes operated. Inby grids of boxes 1, 2, and 4 gone.
280	Feb. 3	...do....	6	Yes...	1	A 1250	2.25	100	0				1	Yes...	Boxes broken up. Grids broken on boxes 1 to 4. 2.2 per cent gas in air current.
282	Feb. 5	...do....	6	Yes...	1	A 1240	.98	500	0	A 950	5	A 750	1	Yes...	Barrier demolished and scattered to A 900.
283	Feb. 8	...do....	6	No...											Flame extended to A 1100. Box 4 operated. 2 per cent gas in air current.

• Tests illustrated by graphs: Test 189, figure 62; test 359, figure 61.

TABLE 57.—Results of tests of type C box barrier—Continued.

Test No.	Date.	Barrier.		Flame.					Maximum pressure.				Remarks.	
				Did explosion reach barrier?	Time from operation of box to arrival of flame.	Ap-prox-imate velocity of flame reaching barrier.	Inby barrier.		Outhy barrier.		Did barrier stop explosion?			
		Box No.	Location of flame.				Station.	Pres-sure.	Station.	Pres-sure.				

a Tests illustrated by graphs: Test 199, figure 62; test 288, figure 61.

Considerable difficulty was encountered in adjusting the chains to the grids satisfactorily. For example, if the chain between the grid and the roof hook was taut it served as a brake to prevent the operation of the box, for when the explosion wave actuated the box it had to pull the grid up through the dust in order that the box might swing far enough to release the suspension bars. In some of the tests there was enough slack (3 to 4 inches) when boxes were loaded, but afterwards the grids sank in the dust and the chains became taut. To prevent this, small blocks were placed between the grids and the bottom boards, but in some tests, when the boxes operated, the supporting blocks became wedged between the side of the box and one of the grids or shelves and prevented the falling of the box frame. In the final arrangement the blocks were made narrow, so as not to block the movement of the grids or shelves.

FAILURES.

Of the nine failures recorded, seven were in the entry and two in the air course. Of the former two utilized four-box and five six-box barriers. Both of the failures in the air course were with six-box barriers. It will be noted that four-box barriers of this type in the air course were uniformly successful, while six-box barriers in the entry frequently failed. Possibly the greater success in the air course may have been due partly to the greater variety of air movements caused by the presence of the butt entries and rooms. It is believed that several of the entry failures were due to the fact that the entry floor at the location of the barrier is usually wet and muddy, and this decreases considerably the amount of dust that rebounds into the air after striking the floor.

Tests 159 and 174 were made during the period of development of the barrier. The failures in these cases were due to improper adjustment of the various parts. After the grids had been so arranged that they would not sink in the dust and draw the chains tight more successful operation was obtained.

In test 161 there was 3.5 per cent of gas in the ventilating current and the explosion was extremely violent. The percentage of gas was so high that it is doubtful if any barrier would be successful. The pressure in by the barrier in this test was beyond the range of the manometer.

The cause of the failure of the entry barriers in tests 178 and 182 is not known. In test 178 the air current contained 2.3 per cent gas; in test 182 it contained 3 per cent. The pressure curves of these tests show a rise of pressure considerably in advance of the tin-foil record, so the explosion was probably much faster than indicated by the records of ruptures of tin-foils. It may be that all of the boxes did not operate quickly enough. The entry barriers in tests 189 and 190

also failed to stop the explosions. In test 189 there was only 0.03 second between the rupture of the E 950 tin-foil and the fall of No. 1 box. This is not time enough for successful operation. Allowance being made for tin-foil lag, it is probable that the front of the flame had passed the box before the box fell. The cause of the failure in test 190 is not evident from the records obtained.

The two failures in the air course were in tests 286 and 358. Both were due to the failure of the barrier to operate soon enough. The records of the various tests showed that the barrier was liable to fail when less than 0.2 second elapsed between the tin-foil rupture and the falling of the first box. In test 286 the elapsed time was 0.13 second for No. 1 box; in test 358 it was 0.17 second for No. 1 box and only 0.05 second for No. 4 box.

The test listed as doubtful was No. 168, in which the flame reached station E 950, but the barrier did not operate. The explosion was very weak and the flame probably would have advanced no further had there been no barrier.

It will be observed that at least three and possibly five of the nine failures were due to the barrier not operating soon enough. To insure quicker operation, a vane-actuating arrangement was connected to a series of boxes and the supporting and operating details changed somewhat. This revised form of barrier was termed the "trough barrier," tests of which are described on page 582.

In conclusion it may be said that although the type C barrier was not always successful it is believed that a barrier of from six to eight boxes, properly constructed and installed, would stop practically any explosion likely to occur in an operating mine in which gas was not a great factor. Many of the tests of the barrier described were very severe; pulverized coal dust was used and the velocities attained approximated the velocities of gas explosions.

TESTS OF V-TROUGH BARRIER.

The V-trough barrier was cheaply and easily constructed of boards 12 inches wide, nailed together at right angles in a V shape, with closed ends. The troughs thus formed extended across an entry near the roof, resting on shallow notched supports in the rib at either end. The pressure of the advance air waves overturns the troughs and dumps the rock dust. Because of its simplicity and ease of construction this barrier was used extensively in the experimental mine testing, but is not considered as reliable as the regular type of trough rock-dust barrier. It has been tried out only in explosions originating at the face of the entry and was used mainly at E 950. The barrier as used, with four exceptions, consisted of 10 to 14 troughs spaced 6 feet apart along the entry. If less than 10 troughs were used, there was too much chance of failure. To make sure of success, 15 troughs

should be used. Plate XIX, *A*, shows a barrier of this type installed in the experimental mine. The results of the tests are given in Table 58.

Eighty-four tests of this barrier were made, in 46 of which the explosion was extinguished before reaching the barrier. The effect on the barrier in these tests varied from complete operation in several cases to the operation of one trough or even none at all. In the earlier tests the troughs were too sensitive, the notch being too shallow, and the entire set would be operated by the cannon shot 350 feet away. There was, moreover, no covering over the troughs and the entire mass of dust was thrown out at once; in a slow explosion it dropped on the floor before the flame reached that section of the entry. These difficulties were overcome by making the notches deeper and by partly covering the top of the trough with a narrow strip of wood along the middle to cause the dust to run out gradually, forming a curtain across the entry under each trough. Sprags were placed in such position that when the trough turned over it would be held on its edge while the dust was falling out. These troughs could be arranged so they dumped in either direction. The notched supporting blocks and sprags can be seen in Plate XIX, *B*, a photograph taken looking toward the source of the explosion.

TABLE 58.—Results of tests of V-trough barrier.

[Barrier loaded with crushed roof shale in all tests.]

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Did barrier stop explosion?	Remarks.	
		Position in entry or air course (stations).	Number of troughs.		Point reached at time of operation of troughs.		Time from operation of trough to arrival of flame.	Approximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
					Trough No.	Location of flame.				Station.	Pressure.	Station.			Pressure.
291	1916 Feb. 26	E 947 to E 905...	8	No...			Sec- onds.	Ft. per sec.	Fed.		Lbs. per sq. in.		Lbs. per sq. in.		Flame extended to E 1150. Barrier operated.
291	..do...	A 947 to A 800...	9	No...											Flame extended to A 1175. Barrier operated.
292	Feb. 29	E 947 to E 893...	10	Yes...	{	1 E 1275..	1.04	{ 2,600	90	E 950..	31	E 750..	19	No...	{ Barrier demolished and scattered to E 850. May have operated too soon.
292a	..do...	A 947 to A 894...	10	Yes...	{	6 E 1265..	.94	{ 2,500	0	A 950..	36	A 750..	19	Yes...	{ Barrier demolished and scattered to A 850. Flame extended to E 1250. Troughs 4
293	Mar. 3	E 947 to E 893...	10	No...		1 A 1250..	.57								and 9 operated to E 1225. Troughs 1
294	..do...	..do...	10	No...											and 10 operated. 0.8 per cent gas in air current.
295	Mar. 6	..do...	10	No...											Flame extended to E 1100. All troughs
296	Mar. 8	..do...	10	Yes...	{	1 E 1260..	2.94	{ 75	0	E 950..	2	E 750..	1	Yes...	operated; six of them thrown down.
297	Mar. 10	..do...	10	No...	{	6 E 1245..	2.88								{ All troughs operated. Troughs 6 to 10 thrown down.
298	Mar. 13	..do...	10	Yes...	{	1 E 1260..	2.91	{ 80	0	E 950..	3	E 750..	1	Yes...	Flame extended to E 1150. Troughs 1, 4, 5, 7, and 10 operated.
299	Mar. 15	..do...	10	Yes...	{	6 E 1255..	2.86	{ 200	0	..do..	4	..do..	2	Yes...	{ All troughs operated. Nos. 4 and 7 thrown down.
300	Mar. 17	..do...	10	No...	{	6 E 1235..	1.60								{ All troughs operated; Nos. 7 to 10 thrown down.
301a	Mar. 20	..do...	10	Yes...	{	1 E 1260..	.67	{ 550	0	E 950..	19	E 750..	9	Yes...	Flame extended to E 1025. All troughs operated; Nos. 4 to 10 thrown down.
302	Mar. 22	..do...	10	Yes...	{	6 E 1260..	.61	{ 500	0	..do..	10	..do..	4	Yes...	{ Barrier demolished and scattered to sta- tion F 700.
		..do...	10	Yes...	{	1 E 1260..	.85	{ 76	0	..do..	10	..do..	4	Yes...	{ All troughs operated. Nos. 5 to 10 thrown down and broken.

303	Mar. 24	do.	10	No.																Flame extended to E 1075. All troughs operated; Nos. 6, 9, and 10 thrown down.
304	Mar. 27	do.	10	Yes	{	1 E 1275.	2.46	600	0	E 950.	8	E 750.	3	Yes						{All troughs operated. Nos. 4 to 10 thrown down.
305	Mar. 29	do.	10	No.		E 1270.	2.38													Flame extended to E 1200. All troughs operated; Nos. 9 and 10 thrown down.
306	Mar. 31	do.	10	Yes	{	1 E 1265.	3.19	150	0	E 950.	2	E 750.	1	Yes						{All troughs operated. No. 10 thrown down.
307	Apr. 3	do.	10	No.		E 1260.	3.14													Flame extended to E 1150. All troughs operated.
308	Apr. 5	do.	10	No.																Do.
314	Apr. 24	do.	10	Yes	{	1 E 1275.	2.67	600	140	E 950.	13	E 750.	6	No.						{All troughs operated. Nos. 5 to 10 thrown down.
315	Apr. 26	do.	10	No.		5 E 1175.	1.20													Flame extended to E 1125. Troughs 6 and 7 operated.
316	Apr. 27	do.	10	No.																Flame extended to E 1225. Barrier not affected.
317	Apr. 28	do.	10	No.																Flame extended to E 1150. All troughs operated except No. 2; Nos. 9 and 10 thrown down.
318	May 1	do.	10	Yes	{	1 E 1275.	2.85	130	0	E 950.	2	E 750.	1	Yes						{Troughs 2, 3, 4, and 9 did not operate; Nos. 5, 6, and 10 thrown down.
319	May 3	do.	10	Yes	{	1 E 1275.	2.84	500	90	do.	14	do.	7	No.						{All troughs operated. All thrown down except No. 2.
320	May 6	E 947 to E 875.	13	Yes	{	1 E 1115.	.44	200	0	do.	4	do.	2	Yes						{Troughs 2, 4, 9, and 13 did not operate; Nos. 5, 6, 8, 10, and 11 thrown down.
321	May 8	do.	13	Yes	{	6 E 1046.	.70	125	0	do.	5	do.	2	Yes						{Troughs 2 and 4 did not operate; Nos. 8 to 13 thrown down.
322	May 10	do.	13	Yes		1 E 1245.	1.73	160	0	do.	4	do.	2	Yes						Do.
323	May 11	do.	13	Yes		1 E 1230.	3.04	50	0	E 950.	2	E 750.	1	Yes						{Troughs 3 and 4 did not operate; Nos. 5 and 6 thrown down. 1.7 per cent gas in air current.
324	May 13	do.	13	No.																Flame extended to E 1100. Troughs 2, 3, 4, 5, 12, and 13 did not operate; No. 6 thrown down. 1.1 per cent gas in air current.
325	May 16	do.	13	No.																Flame extended to E 1175. Troughs 1, 6, 7, 8, and 9 operated.
326	May 17	do.	13	No.																Flame extended to E 1075. Troughs 2, 4, and 13 did not operate.
328	May 24	do.	13	No.																Flame extended to E 1175. Barrier not affected.
329	May 25	do.	13	Yes		1 E 1220.	2.87	70	0	E 950.	3	E 750.	2	Yes						{All troughs operated. Troughs 5, 6, 9, 11, 12, and 13 thrown down.
332	Oct. 9	E 947 to E 881.	12	Yes	{	1 E 1140.	.22	5,000	80	do.	48	do.	16	No.						{Barrier demolished and scattered to station E 750.

* Tests illustrated by graphs: Test 292, figure 67; test 301, figure 2.

TABLE 58.—Results of tests of V-trough barrier—Continued.

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.	
					Point reached at time of operation of troughs.		Time from operation of trough to arrival of flame.	A.P. predicted velocity of flame.	Length beyond barrier.	Inby barrier.		Outby barrier.		
		Trough No.	Location of flame.		Sec-onds.	Ft. per sec.				Station.	Pressure.	Station.		Pressure.
340	1916. Nov. 1	E 947 to E 869...	14	No...										Flame extended to E 1125. Troughs 1, 5, 6, and 7 operated.
341	Nov. 3	do...	14	No...										Flame extended to E 1075. Troughs 1, 5, 6, 7, 9, 10, and 12 operated.
342	Nov. 6	do...	14	Yes...	1	E 1240.	1.06	1,000	0	E 950.	12	E 750.	8	Trough 14 did not operate.
343	Nov. 8	do...	14	No...	4	E 1245.	1.08							Flame extended to E 975. Troughs 1, 5, 6, and 7 operated.
344	Nov. 10	do...	14	Yes...	1	E 1170.	.53	1,300	420	E 950.	18	E 750.	17	Barrier demolished and scattered.
347	1917. Jan. 8	do...	14	No...	4	E 1135.	.34							Flame extended to E 1225. Trough 6 operated.
347	do...	A 947 to A 884...	10	No...										Flame extended to A 1225. Troughs 6 and 7 operated.
348	Jan. 9	E 947 to E 869...	14	Yes...	1	E 1135.	.56	500	0	E 950.	11	E 750.	9	Troughs 8 and 13 did not operate. Nos. 4 and 5 thrown down.
348	do...	A 947 to A 884...	10	Yes...	1	A 1190.	.69	800	0	A 950.	9	A 750.	4	All troughs operated and all thrown down except No. 8.
349	Jan. 11	E 947 to E 869...	14	No...										Flame extended to E 1100. Troughs 8 and 13 did not operate; trough 4 thrown down.
370	Jan. 12	do...	14	Yes...	1	E 1140.	.37	800	0	E 950.	16	E 750.	12	All troughs operated and all demolished except Nos. 1, 2, 3, and 7. 1.0 per cent gas in air current.
392	Mar. 12	E 947 to E 863...	10	No...	5	E 1110.	.83							Flame extended to E 1200. Barrier not disturbed.
392	do...	A 947 to A 884...	10	No...										Flame extended to cut-trough 25. Barrier not disturbed.

393	...do...	E 947 to E 893...	10	Yes...	{	1	E 1255...	1.34	200	0	E 950...	8	E 750...	6	Yes...	{	All troughs operated; Nos. 6 and 10 thrown down.
398	...do...	A 947 to A 884...	10	Yes...		5	E 1250...	1.31	700	0	A 950...	8	A 750...	2	Yes...		Troughs 2, 9, and 10 did not operate. Flame extended to E 1225. Barrier not disturbed.
399	Mar. 23	E 947 to E 893...	10	No...		1	A 1200...	1.08									Flame extended to cut-trough 25. Barrier not disturbed.
400	...do...	A 947 to A 884...	10	No...													Flame extended to cut-trough 25. Barrier not disturbed.
401	...do...	E 947 to E 893...	10	Yes...	{	1	E 1260...	.73	1,100	93	E 950...	13	E 750...	11	No...	{	All troughs operated and all thrown down except No. 9.
402	...do...	A 947 to A 884...	10	Yes...		5	E 1250...	.70	1,500	0	A 950...	19	A 750...	7	Yes...		Barrier demolished and scattered to A 100.
403	Mar. 26	E 947 to E 893...	10	Yes...		1	E 1250...	.59	20	0	E 950...	2	E 750...	1	Yes...		Barrier not disturbed, except that trough 6 was thrown down.
404	...do...	A 947 to A 884...	10	Yes...					50	0	A 950...	2	A 750...	1	Yes...		Troughs 1 to 4 did not operate.
405	Mar. 27	E 947 to E 893...	10	No...													Flame extended to E 1200. Barrier not disturbed. 1.1 per cent gas in air current.
406	...do...	A 947 to A 884...	10	No...													Do.
407	Mar. 29	E 947 to E 893...	10	Yes...	{	1	E 1250...	.69	700	93	E 950...	10	E 750...	10	No...	{	All troughs operated and all thrown down except Nos. 1 and 5. 1.9 per cent gas in air current.
408	...do...	A 947 to A 884...	10	Yes...		5	E 1240...	.63	900	0	A 950...	10	A 750...	4	Yes...		All troughs operated; Nos. 1, 7, and 9 thrown down. 1.9 per cent gas in air current.
409	Apr. 10	E 947 to E 905...	8	No...		1	A 1200...	.78									Flame extended to E 1250. Barrier not disturbed. 1.8 per cent gas in air current.
410	...do...	A 947 to A 884...	10	No...													Do.
411	...do...	E 947 to E 905...	8	No...													Flame extended to E 1000. Troughs 1, 4, 5, 6, 9, and 10 operated.
412	...do...	A 947 to A 884...	10	No...													Flame extended to A 1050. Troughs 3 and 10 did not operate; Nos. 1 and 6 thrown down.
413	Apr. 11	E 947 to E 833...	10	No...													Flame extended to E 1050. Trough 6 only one operated.
414	...do...	A 947 to A 884...	10	No...													Flame extended to A 1075. Troughs 1, 5, and 6 operated; Nos. 1 and 5 thrown down.
415	Apr. 12	E 947 to E 893...	10	No...													Flame extended to E 1150. Barrier not disturbed.
416	...do...	A 947 to A 884...	10	No...													Flame extended to A 1125. Barrier not disturbed.
417	Apr. 13	E 947 to E 893...	10	Yes...	{	1	E 1230...	3.17	80	0	E 950...	2	E 750...	2	Yes...	{	All troughs operated except No. 2. 0.8 per cent gas in air current.
418	...do...	A 947 to A 884...	10	Yes...		5	E 1220...	3.13	100	0	A 950...	2	A 750...	1	Yes...		All troughs operated; Nos. 1, 5, and 6 thrown down. 0.8 per cent gas in air current.
419	Mar. 26	E 947 to E 897...	11	No...		1	A 1250...	2.23									Flame extended to E 1225. Trough 6 only one that operated.

^a Test illustrated by graphs: Test 414, figure 69.

TABLE 58.—Results of tests of V-trough barrier—Continued.

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.	
		Position in entry of air course (stations).	Number of troughs.		Point reached at time of operation of troughs.	Time from operation of trough to arrival of flame.	Approximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
									Station.	Pressure.	Station.	Pressure.		
	1916.				Secs.	Ft. per sec.	Knot.	Lbs. per sq. in.	Lbs. per sq. in.					
470	Mar. 28	do.....	11	Yes	1 E 1275. 3 E 1275. 6 E 1275. 9 E 1275.	4.02 4.10 4.35 4.04	100	0	E 950.	2	E 750.	1	Yes...	Troughs 2, 8, 10, and 11 did not operate.
471a	Mar. 29	do.....	11	Yes	1 E 1275. 3 E 1275. 6 E 1275. 9 E 1275.	2.72 2.75 2.70 2.70	300	0	...do..	8	...do..	4	Yes...	{Trough 8 did not operate; No. 10 thrown down. 1.7 per cent gas in air current.
472	Apr. 1	do.....	11	Yes	1 E 1250. 6 E 1245.	2.60 2.57	100	0	...do..	4	...do..	1	Yes...	All troughs operated.
473	Apr. 3	do.....	11	No.	9 E 1245.	2.56								Flame extended to E 1200. All troughs operated; No. 11 thrown down. 1.6 per cent gas in air current.
474	Apr. 4	do.....	11	No.										Flame extended to E 1000. All troughs operated.
483	Apr. 30	do.....	11	No.										Flame extended to E 1150. All troughs operated.
489	May 14	do.....	11	Yes	1 E 1240. 6 E 1240. 11 E 1210.	.88 .88 .78	550	0	E 950.	9	E 750.	4	Yes...	{All troughs operated; Nos. 9, 10, and 11 thrown down. 2.2 per cent gas in air current.
490	May 17	do.....	11	No.										Flame extended to E 1125. All troughs operated. 1.9 per cent gas in air current.
491	May 18	do.....	11	No.										Flame extended to E 1200. Trough 6 was only one that operated.
492	May 20	do.....	11	No.										Flame extended to E 1175. No troughs operated. 1.8 per cent gas in air current.
493	May 21	do.....	11	No.										Flame extended to E 1150. All troughs operated except No. 8.
494	May 22	do.....	11	Yes	6 E 1245. 11 E 1240.	1.16 1.10	600	0	E 950.	8	E 750.	4	Yes...	{All troughs operated; No. 8 thrown down.

a Test 471 is illustrated graphically by Figure 64.



SIDE VIEW OF TYPE A CONCENTRATED BARRIER, AFTER DUMPING.



VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON TYPE B CONCENTRATED BARRIER.

Explosions reached the barrier in 38 trials. The barrier stopped the explosion 31 times and failed 7 times. A weak explosion operated the troughs, usually throwing some of them down. A violent explosion demolished the whole barrier, scattering the dust over a considerable area. The first failure (test 292) was due to the barrier being too sensitive and dumping all the dust at one time, as already described. The causes of the remaining six failures (tests 314, 319, 332, 344, 400, and 403) are not so evident. All these failures were in the entry, the barrier having 10 to 14 troughs. With several types of barriers it has been observed that most of the failures were in the entry, the same type of barrier operating successfully in the air course. The only apparent difference was that the butts and rooms were in the air course and the floor under the barrier in the air course was dry, but under the barrier in the entry it was usually wet and muddy. The muddy floor might prevent the rebound of the dust in the entry, thus reducing the efficiency of the barrier. These failures were all in explosions ranging in strength from medium to violent. It is evident, however, that while the barrier is easily and cheaply constructed and has served the purpose of stopping experimental explosions it is, on the whole, not as reliable as some of the other types described.

TESTS OF CONCENTRATED BARRIER.

The concentrated barrier consists of two large, shallow containers of incombustible dust, which are placed overhead across the entry-way and are supported near the roof by hinges and catches. The latter, in turn, are held by a leverage system so adjusted that the system is released when the pressure of an advancing air wave, operating swinging vanes, reaches a predetermined amount. The vanes are hinged planks extending across the entry just beneath the roof, 100 feet or more from the barrier on each side; the pressure on these vanes is converted into a pull by a chain passing around a pulley, and transmitted by a strong wire from the chain to the releasing mechanism. When the catches are released the containers, which are hinged at one end, swing downward under the heavy load of rock dust. A detailed description of this barrier and its mode of operation is given on page 569. The operation of the barrier, or its demolition, throws a great quantity of dust into the entry, making a dense rock-dust cloud that effectually blankets the flame or cools the gases below the ignition temperature.

Two types of barriers, A and B, were tested in the experimental mine. In the A type the dust compartments are boxes, one end falling to the floor when the barrier operates and giving the appearance of an inverted V. Plate XX shows such a barrier after operation. The

dust compartments actually block the entry except for spaces at each side, and as the operation occurs before the explosion reaches this point this blocking of the entry increases the resistance to the advance of an explosion and tends to check the explosions, particularly those of no great violence.

It was believed, however, that except in entries seldom used such barriers might menace the safety of passing men and animals, since accidental operation and the falling of the heavy compartments might injure those who chanced to be passing under. For this reason type B was designed. In a barrier of this type the bottom boards of the compartment are not connected with each other or to the side frames of the box, and when the barrier is operated their fall is checked short distances below the original position by chains supported from the timbers or the roof; accidental operation would therefore not be as dangerous to those passing beneath as are the falling ends of boxes of the A type.

After loading the compartment and raising it to position the side frame is fastened to the framework and the bottom boards are supported at the free ends by an angle iron, which in turn is supported by a system of levers. Plate XVIII, B (see p. 460), shows a type B barrier in position in the mine entry. When the barrier is operated, the angle-iron support is withdrawn and the bottom boards drop; alternate boards fall 9 inches before they are caught by chains from the roof, and intervening boards fall 18 inches. Plate XXI shows the appearance of this type of barrier after test 120. Checking the fall of the boards at the points shown serves a good purpose—that of holding a large quantity of dust near the roof. If the barrier operates some time before the flame reaches it, a large quantity of dust is still available near the roof to be blown into the air current by the waves of greater pressure which accompany the flame. Plate XXII, A, shows the effect of a violent explosion on a B type concentrated barrier.

In Table 59 information is given concerning 10 tests in which the concentrated barrier was used; in two of these the A type was tested, in the remaining eight the B type. Records of the operation of the advance vane, the bumping vane, and the barrier boxes were obtained in many tests by arranging circuits so that the movement of any of these objects would break them. The bumping vane is set near the tripping lever of the barrier, and should the wire from the advance vane fail to cause tripping it was thought the movement of the bumping block attached to the nearby vane would cause the lever to trip.



A. VIEW SHOWING EFFECT OF VIOLENT EXPLOSION ON TYPE B CONCENTRATED BARRIER.



B. ROCK-DUST-PROTECTED STOPPING, BEFORE CURTAINS ARE HUNG.



A. VIEW SHOWING EFFECT OF STRONG EXPLOSION ON ROCK-DUST-PROTECTED STOPPING.



B. ROCK-DUST-PROTECTED VENTILATING DOOR, END BOARD OF UPPER COMPARTMENT HAS BEEN REMOVED TO SHOW CHAINS.

TABLE 59.—Results obtained from tests of concentrated barrier.

Test No.	Date.	Barrier.			Flame.				Maximum pressure.				Remarks.			
		Position in entry (stations).	Type.	Loading.	Operation after ignition.		Did explosion reach barrier?	Location at operation of box (station).	Time from operation of box to arrival of flame.	A.P. proximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.		
					Barrier part.	Time.						Pressure.			Station.	Pressure.	Station.
						Secs.				Ft. per sec.	Fed.	Lbs. per sq. in.	Lbs. per sq. in.			
103	1914. Apr. 13	E 805 to E 790.	A	Limestone.			Yes				65	E 950	E 750		Yes	Coal dust outby barrier not ignited. Barrier partly destroyed.
106 ^a	Apr. 13	do.	A	do.	{O vane B vane Box...	{0.35 .52 .41	{Yes Yes No	E 1220	0.42	2,000	65	E 950	E 750	10	Yes	{Coal dust outby barrier not ignited. Flame extended to E 825. Barrier operated and partly broken.
108	Apr. 27	do.	B	do.	{O vane B vane Box...	{.44 .50 .45	{No Yes Yes									{Coal dust outby barrier not ignited. Barrier partly destroyed.
109 ^a	Apr. 29	do.	B	do.	{O vane B vane Box...	{.45 .49 .69	{Yes Yes Yes	E 1205	.83	700	0	E 960	E 750	7	Yes	{Coal dust outby barrier not ignited. Barrier partly destroyed.
114	May 12	do.	B	do.	{O vane B vane Box...	{.95 1.03 1.54	{Yes Yes Yes	A 890	1.35	600	0	E 960			Yes	{Ignition at face of No. 1 butt. Barrier demolished. Coal dust out-
120	June 11	E 700 to E 685.	B	Shale.	Box...	5.44	Yes	E 1070	1.25	100	0	E 750	E 550	0	Yes	{by barrier not ignited. Coal dust zone outby barrier not ignited. E 700 match not burned.
126	June 22	do.	B	do.	{O vane B vane Box...	{.49 1.56 .61	{Yes Yes Yes	E 1275			10	E 750	E 550	6	Yes	Barrier demolished.
141	Oct. 9	do.	B	Limestone.			Yes				0	E 750	E 550	16	Yes	{Ignition at face of No. 2 butt. Coal dust outby barrier not ignited. Barrier demolished.
435	1918. May 6	do.	B	Shale.	{O vane Box...	{.48 .62	{No Yes									{Barrier operated. Three chains broken.
436	May 7	do.	B	do.	O vane	.47	Yes	E 1210	3.80	100	0	E 750			Yes	{Coal dust outby barrier not ignited. Four chains broken, dropping boards to floor.

^a Tests illustrated by graphs: Test 105, Figure 10; test 109, Figure 15.

In test 103 the original form of A type barrier was used. This form had boxes about 7 feet square and held about 3.5 to 3.75 tons of limestone dust. The advance vane was at E 900. The maximum pressures developed by the explosion were relatively low, being only 5 pounds at the nearest station (E 950) inby the barrier, but the barrier operated successfully; the outby box was partly wrecked. No record was obtained of the time of the barrier operation. The flame^{49a} extended to a point 65 feet outby the barrier, but the coal-dust auxiliary zone was not ignited.

In test 105 the installation was similar, but the pressures developed were greater, the maximum at E 950 being 29 pounds. Operation of the barrier was successful in stopping the explosion, the coal dust beyond not being ignited.

A type B barrier was used in test 108. Each bottom board had three transverse boards nailed to it; these boards, spaced about 1½ feet from each other and the ends of the boards, were to assist the retention of a large amount of dust near the roof. The explosion was very feeble and did not reach the barrier. The barrier was, however, operated and some of the boards were broken by the fall.

The B type barrier was successful in six out of the seven remaining tests, the flame not reaching the barrier in the seventh. The pressures developed at the stations nearest the barrier ranged from 5 to 50 pounds. It is interesting to note that in tests 114 and 120 a match in the roof at the inby end of the barrier was not burned, probably because the operation of the barrier made a dense cloud that screened the match. Test 126 is the only one in which the bumping-vane record was later than the barrier-box record. Inasmuch as in the other tests both the advance-vane and the bumping-vane records were obtained almost simultaneously before the barrier operated, there is some doubt as to which vane operated the barrier.

The concentrated barriers did not fail in any trial. It is believed that an advance vane is a very desirable feature for a barrier, as it increases the likelihood of operation before the arrival of the flame. The physical blocking of the entry by the operation of the A type barrier is also desirable, but where its installation would menace the safety of those who must travel beneath it the B type barrier is an efficient substitute.

Early in the summer of 1915 a concentrated barrier was erected in the air course at A 600-A 575. This barrier was in place when testing began in the fall. Being some distance from the source of the explosions and outby the butts, it was not affected by tests 226 to 236, all of which were weak explosions. Test 237 was a standard ignition test on pure pulverized Fire Creek coal dust. A violent explosion resulted, the pressure at A 950 being 75 pounds and that

^{49a} Indicated by burnt guncotton.

at A 750 27 pounds. The flame was extinguished at A 950 by a type C box barrier, but the pressure at A 600 was sufficient to demolish the concentrated barrier completely, all the heavy timbers being torn out.

A concentrated barrier was again installed at E 700 prior to test 485. Propagation was not obtained in test 485, the flame extending to E 1175. Despite this fact the air waves sent out by the explosion were strong enough to cause operation of the barrier. In test 486 an explosion was obtained with moderate pressures and low velocities near the barrier, which operated, extinguishing the flame. There was no indication of flame on the outby side of the barrier, a pure coal-dust zone failing to ignite.

TESTS OF VENTILATING-DOOR BARRIER.

It has been noted in all mine explosions that the ventilating doors and frames in the path of the explosion have invariably been carried away. This fact suggested to the senior author the desirability of designing a door frame enclosure which would itself act as a rock-dust barrier, as such doors are always at critical points, that is, near the entrance of air splits or panels.

The rock-dust-protected ventilating-door barrier consists of an ordinary mine door the frame of which, bounded on the sides and at the top by collapsible rock-dust compartments, holds the side boards in position by bracing them against timbers on the opposite side. If an explosion blows the door and frame out, the support of the side and upper compartments is withdrawn and the dust inclosed in them falls in the entry. Plate XXIII, *B*, (see p. 475) shows such a barrier with the end board removed to show chains that check the fall of the bottom boards of the upper compartment, an arrangement similar to that in the type B concentrated barrier previously described. A detailed description of this barrier and its mode of operation appears on page 570.

Eight tests were made on this form of barrier, the results being given in Table 60. In test 120 two door barriers were built. The one at 1 LB 15 had the door opening toward the inby side, whereas the one at 2 LB 15 had the door opening outby. Neither barrier had chains for checking the fall of the lower boards of the upper compartment; consequently, when the barrier operated no dust was retained near the roof of the entry. It is probable that on this account the flame passed over the barrier in No. 2 butt, and it is possible that it passed through the barrier in No. 1 butt, although the latter probably operated when the flame appeared.

TABLE 60.—*Results of tests on ventilating-door barrier.*
 [Limestone dust used, except in test 140, in which shale dust was used.]

Test No.	Date.	Location of barrier (station).	Did explosion reach barrier?	Flame.				Maximum pressure.				Remarks.	
				Location at time of operation of barrier to (station).	Time from operation of barrier to arrival of flame.	Approximate velocity on reaching barrier.	Length beyond barrier.	Inby barrier.		Outby barrier.			
								Station.	Pressure.	Station.	Pressure.		
					Seconds.	Feet per second.	Feet.		Lbs. per sq. in.		Lbs. per sq. in.	Did barrier stop explosion?	
120	1914. June 11	1LB 15	Yes...	Passed barrier.	—0.40	300	200					No...	Barriers in test 120 not provided with chain to support bottom of top compartment; this is cause of failure in No. 2 butt.
120	do.	2LB 15	Yes...	E 1275	3.90	300	225					No...	Barrier demolished and scattered to station E 350.
128 ^a	July 11	E 944	Yes...	E 1260	.48	1,700	0	E 960	63	E 760	10	Yes...	Barrier demolished and scattered to station A 400.
133	do.	A 944	Yes...	E 1260	.44	1,800	0	A 960	86			Yes...	Barrier thrown down; five top shelves left hanging.
139	July 15	E 945	Yes...	E 1275	.76	200	0	E 960	25			Yes...	Barrier thrown down; pieces scattered to station A 450.
139	do.	A 890	Yes...	E 1275	1.00			A 960	17	A 750	0	Yes...	Barrier thrown down; many top shelves left hanging.
140	Oct. 1	A 875	Yes...				0	2B 50	7			Yes...	Barrier thrown down; a few top shelves left hanging.
141	Oct. 9	A 875	Yes...				35					Yes...	Barrier thrown down; a few top shelves left hanging.

^a Test 133 illustrated by graph, figure 17.

In the other tests of this series the construction of the door was revised to include chains to check the fall of the floor boards of the upper compartment; all tests made on the barriers with this arrangement were successful.

Tests 138 and 139 were prepared to try the operation of two doors in each test, the first explosion to be violent, the second of moderate pressure. In these tests the air-course door was so arranged that it opened outby while the entry door opened inby. The opening of the door outby would decrease the available surface on which the pressure could act to blow out the door and would limit the effective area on which the pressure could act nearly to the area of the doorframe. However, as the doorframe was not braced to withstand pressure from the side opposite the door, not much force would be required to blow it down.

In the entry the pressure would force the door against the frame, leaving the whole surface available for pressure to act on; the frame, however, is only slightly braced against this action, enough to prevent the slamming of the door in ordinary mine operation from knocking down the frame. The bracing increases the resistance to the blowing out of the frame, but this resistance is easily overcome because of the great area the pressure can act on. The results in tests 138 and 139 indicate that there was practically no difference in the operation of the doors, although one door opened toward the explosion and the other opened away from it.

In tests 140 and 141 the ventilating doors were installed in the air course between the butts, with the door opening inby. In both tests the door barrier successfully stopped the explosion; the hanging shelves were more or less broken.

The tests of the ventilating-door barriers show them to be efficient in stopping explosions, and their installation in mines might be of great service in limiting the extent of an explosion.

A rock-dust-protected ventilating door was erected in the summer of 1915 in the air course between the butt entries. The door was loosened by the very weak tests 226 to 234, in none of which the flame extended more than 75 feet from the igniting cannon. In test 235, however, a weak propagation was obtained in which the flame reached A 950, generating pressures of about 5 pounds per square inch. The flame was stopped by a C type box barrier, but the pressure was enough to cause the collapse of the door between the butt entries. Had the flame passed the box barrier it would probably have been extinguished by the door barrier.

TESTS OF ROCK-DUST STOPPINGS OR ROCK-DUST-PROTECTED STOPPINGS.

The first form of rock-dust stopping tested was two board walls with a 1-foot space between, filled with rock dust. Such a barrier was built across the mouth of No. 1 right butt in test 120. A barrier of this type presents a large surface for the explosion to act on, and the shock wave is likely to blow it down. According to the records of this test the barrier was broken 0.47 second after the ignition shot was fired, but the tin-foil at E 850, the next station inby, was not burned until 5.76 seconds after the firing. No indications of flame having passed inby the stopping were present.

Five tests of the revised or final form of stopping were made. This form consisted of two vertical sets of five or six horizontal dust-filled shelves each about 12 inches wide, arranged with a space of about 1 foot between sets. Plate XXII, *B* (see p. 474), shows such a set of shelves installed in a mine. Short waterproof curtains are hung from shelf to shelf to keep the rock dust dry in the summer season or in a wet place. Plate XXIV, *A*, shows the appearance of the barrier with curtains installed. These sets may also be built on both sides of any kind of a stopping.

It is well known that stoppings are usually blown out in explosions, a light pressure over their large area sufficing to overthrow them. If rock-dust shelves are built on both sides of stoppings in passages connecting districts or panels, it is thought they will limit effectually any explosions reaching such points. If the explosion pressure is great, the stopping and both sets of shelves are broken and a dense cloud of stone dust results. However, if the explosion is light, although the stopping and the set of shelves away from the advancing explosion may be blown down, the other set will remain in position and the pressure waves blowing through the shelves will project the stone dust into the air as a thick cloud. Plates XXIV, *B*, and XXIII, *A* (see p. 475), show the results of a light and a strong explosion on a rock-dust-protected stopping. The results of the tests are given in Table 61.

In tests 139 and 140 practically all of the barrier was blown down, but in tests 141 and 148 the set of shelves on the side toward the advancing explosion remained in position. About two-thirds of the dust was blown off the shelves which still stood. In no test was flame detected beyond the barrier. This showing is very good, particularly in tests 141 and 148, in which coal dust loaded on cross shelves beyond the barrier, in each test, was not ignited.



A. ROCK-DUST-PROTECTED STOPPING, AFTER CURTAINS ARE HUNG.



B. VIEW SHOWING EFFECT OF LIGHT EXPLOSION ON ROCK-DUST-PROTECTED STOPPING.



OPERATION OF A SINGLE-TROUGH ROCK-DUST BARRIER IN OPEN AIR.

TABLE 61.—Results of tests of rock-dust-protected stoppings.

Test No.	Date.	Stopping.		Did explosion reach stopping.	Flame.				Maximum pressure.				Did stopping stop explosion?	Remarks.
		Location (stations).	Loading.		Location at time of operation of stopping (stations).	Time from operation of stopping to arrival of flame.	Approximate velocity on reaching stopping.	Length beyond stopping.	Inby stopping.		Outby stopping.			
									Station.	Pressure.	Station.	Pressure.		
					<i>Seconds.</i>	<i>Ft. per sec.</i>	<i>Fed.</i>	<i>Lbs. per sq. in.</i>		<i>Lbs. per sq. in.</i>				
120	1914, June 11	1RB 15	Shale	Yes	E 1275 5.40	300	0	A 950	17				Yes	Stopping had no shelves.
139	July 15	2LB 16	do.	Yes	E 1285 1.05	200	0						Yes	Stopping entirely blown out.
140	Oct. 1	C. T. 2B 200	do.	Yes									Yes	One center and two side posts left standing.
141	Oct. 9	do.	Limestone	Yes			0						Yes	Shelves in No. 2 butt side remained up; others thrown down and broken.
141	do.	1RB 15	do.	Yes			0	A 750	39				Yes	Stopping demolished and scattered to face of right butt.
148 ^a	Dec. 4	C. T. 2B 200	do.	Yes		400	0	2B 250	11	1B 50	7		Yes	Shelves in No. 2 butt side remained up; others blown down.

^a Test 148 illustrated by graph, figure 77.

TESTS OF TROUGH BARRIER.

The trough barrier comprises six or more troughs about 21 inches wide, 12 inches or more deep, and the full width of the entry, which are set 6 feet apart transversely in an entry, just beneath the roof, and rest on side supports. The bottom boards of the troughs are held in position by a lever system that is released when the movement of an advance vane is transmitted to tripping levers by wires. When the lever supports are withdrawn, the bottom boards fall out and showers of dust fall in the entry. There are breaker bars of wood inside the troughs, which break up the mass of dust as it falls into the entry. The bottom boards are caught by chains at various distances below their original positions. A detailed description of this barrier and its mode of operation is given on page 582. Plate XIX, *B* (see p. 466), shows such a barrier installed in a mine; the wires can be seen stretched forward along the ribs to the advance vane. Plate XXV shows the dust falling from a single trough operated by hand. (See p. 481.)

The vane for this barrier as designed had an area of 8 square feet and a current velocity of 100 feet per second was supposed to produce enough pressure to operate the barrier. This barrier is easy to construct and requires a minimum of head room. Use of the advance vane insures its action. The shower from the box may last 10 seconds; this shower and the dust caught on hanging shelves give a long period of effective dust cloud formation. The barrier is therefore believed to be possibly one of the most convenient to install of all the inclosed rock-dust barriers, and the tests indicate that it is also one of the most effective in operation.

The trough barrier was used in 32 tests, being located at E 950 in all of them. Results of these tests appear in Table 62. Flame did not reach the barrier in 18 of the 32 tests. Ten of these 18 tests were short-zone ignition tests and it was not expected that the flame would reach the barrier. Of the remaining eight, four were standard ignition tests and four were standard propagation tests, in which the flame reached points between E 1250 and E 1000.

TABLE 62.—Results of tests of trough barrier.
[Troughs are located beginning at station E 947, spaced 6 feet center to center.]

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.						Maximum pressure.		Remarks.
					Location of flame at time of operation of troughs.	Time from operation to arrival of flame at troughs.	Approximate velocity on reaching barrier.	Length beyond barrier.	Station in by barrier (E 950).	Station out by barrier (E 750).	Did barrier stop explosion?		
		Trough No.	Flame location (station).									Seconds.		Ft. per sec.	Feet.	Lbs. per sq. in.	Lbs. per sq. in.
193	1915. Mar. 23	6	Shale.....	No.								Flame extended to E 1200. Troughs released on one side.	
194	Mar. 24	6	do.....	Yes	Vane. 1 6	E 1200. E 1200. E 1200.	0.33 .33 .33	800	35		15	Yes... { Coal-dust out by barrier not ignited. Barrier demolished. 1 per cent gas in air current.	
195	Mar. 29	6	do.....	Yes	Vane. 1 6	E 1275. E 1270. E 1270.	2.63 2.50 2.49	650	0	11	5	Yes... { Coal-dust out by barrier not ignited. Troughs 4, 5, and 6 demolished.	
196	Apr. 2	6	do.....	No.								Flame extended to E 1100. Barrier operated.	
197	Apr. 6	6	do.....	Yes	Vane. 1 3 6	E 1275. E 1260. E 1195. E 1255.	2.41 2.31 1.84 2.28	100	0		1	Yes... { Coal-dust out by barrier not ignited. Troughs 1 and 2 thrown down and broken.	
199 ^a	Apr. 9	4	do.....	No.								Barrier operated. Trough 4 thrown down and broken.	
201	Apr. 13	6	do.....	Yes	Vane. 1 3 6	E 1275. E 1275. E 1275. E 1200.	1.27 1.12 1.10 1.11	570	0		7	Yes... { Coal-dust out by barrier not ignited. Barrier demolished.	
202	Apr. 17	6	do.....	Yes	1 3 6	At barrier. do	.66 — .21 — .24	800	0	10	6	Yes... Do.	
203	Apr. 21	6	do.....	No.								Flame extended to E 1175. Troughs 1 and 2 operated on one side only.	
204	do.....	6	do.....	Yes	1 3 6	E 1160. E 650. E 1060.	.42 — .43 — .09	400	315	9	15	No... { Coal-dust out by barrier ignited. Troughs 1 to 4 thrown down and broken. Small vane used did not give sufficient surface. 1 per cent gas in air current.	
206	Sept. 29	6	do.....	No.								Flame extended to E 1275. Trough 1 operated.	
227	do.....	6	do.....	No.								Flame extended to E 1250. Barrier not affected.	
228	Sept. 30	6	do.....	No.								Do.	
229	do.....	6	do.....	No.								Do.	

^a Tests illustrated by graphs: Test 199, figure 54; test 347, figure 60.

TABLE 62.—Results of tests of trough barrier—Continued.

Test No.	Date.	Barrier.		Did explosion reach barrier?	Flame.				Maximum pressure.		Did barrier stop explosion?	Remarks.
		Num-ber of troughs.	Loading.		Location of flame at time of operation of troughs.	Time from operation to arrival of flame at troughs.	Approximate velocity on reaching barrier.	Length beyond barrier.	Station in by barrier (E 950).	Station out by barrier (E 750).		
					Trough No.	Flame (location station).	Ft. per sec.	Fed.	Lbs. per sq. in.	Lbs. per sq. in.		
220	1915.	6	do.	No.								Flame extended to E 1200. Trough 1 operated.
221	Oct. 4	6	do.	No.								Flame extended to E 1200. Troughs 1 and 5 tripped.
222	Oct. 7	6	do.	No.								Flame extended to E 1200. Barrier not affected.
223	Oct. 8	6	do.	No.								Flame extended to E 1175. Trough 1 operated.
224	Oct. 9	6	do.	No.								Flame extended to E 1225. Barrier not affected.
225	Oct. 11	6	do.	Yes.			450	0	3	2	Yes.	Trough 1 thrown down and broken. Troughs 4, 5, and 6 operated on one side only.
226	Oct. 14	6	do.	No.								Flame extended to E 1100. Trough 1 operated.
227	Oct. 18	6	do.	Yes.								Trough 2 operated on one side only.
228	Oct. 19	6	do.	Yes.	1 Passed barrier.	.34	2,000	100	44	26	Yes.	Barrier demolished and scattered to E 550.
229	Nov. 9	6	do.	Yes.	5 E 1070.	.30	500	125	8	6	No.	(All troughs operated. Troughs 5 and 6 thrown down.)
230	Nov. 12	6	do.	No.								Flame extended to E 1250. Barrier did not operate. 2 per cent gas in air current.
231	Nov. 13	6	do.	No.								Flame extended to E 1200. All troughs operated.
232	Nov. 15	6	do.	No.								Trough 6 thrown down. 1.9 per cent gas in air current.
233	Nov. 16	6	do.	No.								Flame extended to E 1175. Barrier did not operate.
234	Nov. 17	6	do.	Yes.								Barrier demolished and scattered to E 650.
235	Nov. 18	6	do.	Yes.	Vane. E 1275.	.50	1,500	0	30+	13	Yes.	Flame extended to E 1000. All troughs operated.
236	Nov. 19	6	do.	No.	E 1130.	.12						Barrier demolished and scattered to E 600.
237	Nov. 20	6	Kieselguhr	No.	E 980.	.02						
238	Nov. 22	6	do.	Yes.	Vane. E 1275.	.77	800	0	18	7	Yes.	Barrier demolished and scattered to E 600.
239	1916.	6	Shale	Yes.	1 E 1270.	2.12	100	0	6	2	Yes.	All troughs operated. Troughs 4 to 6 thrown down.
240	Feb. 17	6	do.	Yes.	1 E 1270.	.49						
241	Oct. 16	6	do.	Yes.	4 At barrier.	.11	2,000	0	30	15	Yes.	Barrier demolished and scattered to E 600.
242	Nov. 17	6	do.	Yes.	Vane. E 1270.	.55						
243	Nov. 17	6	do.	Yes.	1 E 1240.	.42	6,000	317	115	48	No.	Barrier completely destroyed.
244	Nov. 17	6	do.	Yes.	4 E 1150.	.12						
245	Nov. 17	6	do.	Yes.	6 At barrier.	.00						

• Tests illustrated by graphs; Test 190, figure 64; test 247, figure 60.

Flame reached the barrier in 14 tests, and in 11 of these the barrier stopped the explosion. The three failures were in tests 204, 242, and 347. The troughs, as is shown by the time records, usually operated well in advance of the flame; moreover, there were ordinarily short periods of time between the operation of the boxes, probably because of the time required to take up the small amount of slack in the wires connecting the tripping levers of the different troughs.

In test 204 a vane of smaller size than that specified was used to determine if such a vane would operate the barrier properly. The vane was not large enough and the barrier failed. Test 237 was an ignition test of pure pulverized Fire Creek coal dust, and the explosion was very strong. The barrier was not wired, and consequently no record of its operation was obtained, but the vane was broken in two pieces and badly splintered, the pulley supports were bent, and the chains so tangled that the vane could not have acted properly. The barrier, nevertheless, checked the flame, as is shown by the reduction in pressure; the flame reached 100 feet outby the barrier, but there was no indication of its extending further, so the barrier was not deemed to have failed.

In test 242 the barrier did not operate soon enough, No. 1 trough not operating until after the flame passed. This failure may have been caused by the wire from the vane catching in some nails driven in the under side of one of the cross shelves. Test 347 was an ignition test with pure 20-mesh Lower Kittanning coal dust. A tremendously violent explosion resulted, the pressure at E 950 immediately inby the barrier being 115 pounds per square inch. The indicated flame velocity from E 1050 to E 950 was over 7,000 feet per second, and although this high figure might be due to a small error in the time of rupture of one of the tin-foils there can be no doubt that the explosion was traveling at least 5,000 feet per second when it reached the barrier. The vane and pulleys were smashed and the chains jammed in them. The troughs were completely destroyed, no pieces large enough to identify being found. Wrecking of the vane may have been responsible for the barrier failure, but the high pressure and velocity of the explosion would have made difficult the successful operation of any barrier. That the barrier had considerable effect on the explosion is shown by the fact that the pressure dropped from 115 pounds at E 950 to 48 pounds at E 750.

Although test 347 has been held a failure, in the absence of coal-dust loading outby the barrier, it is not certain that it was a complete failure, because without a barrier the explosion would probably have extended to the mouth of the entry.

CONCLUSIONS REGARDING DUST BARRIERS.

The original Taffanel dust barrier is effective, when the dust is fresh, in stopping the majority of explosions, and has the great merit of simplicity; it is however, likely to fail in slow-moving explosions. In general it is not suited to American coal mining for these reasons: Coal dust is apt to accumulate rapidly and mantle the rock dust. In the summer months the rock dust tends to get moist and cake, so that it is unsuited for loading a barrier; moreover, most American mines use the watering method of rendering coal dust inert, thus preventing the employment of open dust barriers, as wetting makes the dust valueless.

The closed barriers are covered over with oilcloth or light tarpaulin to protect the rock dust from contamination with coal dust and from getting wet; in the concentrated barrier the coal dust is entirely inclosed. Later types are much more sensitive than the Taffanel barriers and are suitable as a secondary protection in mines employing either the watering method or the general rock-dusting method. In development there was necessarily a considerable number of failures, but it is believed that the latest types of barriers will under almost all conditions be successful in arresting or limiting explosions. Nevertheless, it is not recommended that entire dependence be placed on them, especially in gaseous mines. General rock dusting, or watering, should also be used.

The important features of these later types are (1) the employment of actuating vanes placed in advance on either side of the barrier to provide for very fast explosions; (2) the design for cascading the dust and retaining some on shelves in the upper part of the entry in case the explosion flame is delayed in reaching the barrier after the latter has been tripped. The preferable types are the concentrated barrier, which by being recessed in the roof where the entry is low, presents no obstruction to ventilation or haulage; and the trough barrier, which is especially suitable for use where the passageway is high. Both of these types operate by advance vanes, or independently by supplemental vanes at the barriers in case the advance vanes are in defective condition.

The special dust barriers in connection with ventilating doors, overcasts, and cross-cut or cut-through stoppings are recommended for special places. All of these closed barriers are of simple construction and can be built easily by the mine blacksmith and carpenter.

CHAPTER X.—MISCELLANEOUS DATA.

PART 1.—INSTRUCTIONS AND FORMS FOR USE IN SAMPLING MINE DUST AND GASES AND OBTAINING DATA RELATED THERETO IN DETERMINING THE EXPLOSION HAZARDS OF A MINE.

In Chapter VI, on the tests of coal other than Pittsburgh, reference was made on pages — and — to the methods of taking samples in the mine. These methods were developed as the testing proceeded, earlier samples being accompanied by less complete information than later ones.

The method of procedure in obtaining and testing a large sample of coal from a commercial mine may be summarized as follows: After permission has been obtained from the operator to take a sample one of the bureau's engineers visits the mine. He obtains face samples of the coal, road-dust samples, rib-dust samples, and mine-air samples and directs the taking and boxing of a large sample for shipment to the experimental mine. These samples are all obtained in accordance with the printed instructions on the forms hereto appended. The samples are taken to represent as nearly as possible the conditions over the entire mine and, if possible, to give some idea of what conditions may be expected in future development. It may happen that some large section of a mine—some one panel, for example—will be found to be in a more dangerous condition throughout than the remainder of the mine. Samples of dust should, of course, be taken to show the danger of this section, and the section should be treated accordingly, rather than by averaging its condition with that of the mine as a whole.

The forms known as the "A B C sheets," hereinafter given, are filled as completely as possible. The road-dust, rib-dust, mine-air, and coal-face samples are sent to the laboratory in Pittsburgh for analysis, accompanied by cards giving data on the samples in question, one card being prepared for each sample. A copy of each card is appended. These cards are filled out on both sides. The report sheets are forwarded to the mining division in Pittsburgh and the large sample to the experimental mine. When the sample arrives at the experimental mine, a series of tests, as previously described, are made to obtain the explosibility limits of the coal under test conditions. After explosibility limits have been ascertained under such

conditions, proper allowance can be made for actual mine conditions, where the latter differ materially from the test conditions. Considerable caution is exercised in doing this, the idea being that an error on the side of safety will cause no harm, while an error on the side of danger might invite disaster. In the test work it is essential that the conditions be kept standard to obtain accurate and comparative results. Only through such standardization was a mass of information obtained from the tests described in this bulletin.

After these tests are completed, the analyses of all the samples, the reports from the mine, and the results of the explosion tests are assembled and a general report thereon is prepared for the operator. This report gives the conditions as found in the mine, the analyses of the samples, the results obtained from the explosion tests, and the conclusions that may be drawn on the relative danger of an explosion. Recommendations are added concerning mining methods, which may, in the opinion of the bureau's investigators, be modified so as to attain greater safety. An outline of one of these reports appear on another page after the forms for reporting mine conditions. The outline is essentially the same for all mines investigated. Reports on different mines differ considerably with conditions in the mines, but the divisions of the report and the method of treatment are essentially the same for all. The subject matter on the various coals given in Chapter VI has been obtained, for nearly all mines, by abridging the original reports sent out after explosion tests of the coals.

The instructions and report forms follow:

FORM GIVING INSTRUCTIONS FOR COAL SAMPLING.^a

DEPARTMENT OF THE INTERIOR,

BUREAU OF MINES.

INSTRUCTIONS FOR STANDARD FACE SAMPLING OF COAL.

(From Technical Paper 1 of Bureau of Mines.)

Use standard sampling outfit of the Bureau of Mines. Determine tentatively the places for taking samples from mine map in office, bearing in mind that some of samples should indicate character of coal available for future as well as present workings. If a considerable amount of coal in the future is to be taken from present standing pillars one or more pillar samples should be taken, face and pillar samples being proportioned.

Take no less than 4 samples in any mine.

For daily output of 600 tons, take not less than 5 samples.

1000	"	"	"	"	"	6	"
1500	"	"	"	"	"	7	"
3000	"	"	"	"	"	8	"

Before cutting sample face of coal should be cleared of loose coal, etc., for a width of about 5 feet. In the center of this cleared area the coal should be cut away with a pick to a depth of at least 1 inch and a width of 1 foot from roof to floor to square up face and remove weathered coal.

Clean off floor, spread sampling cloth and make a cut 2 inches deep and 6 inches wide or 3 inches deep and 4 inches wide in the softer coals from the roof to the floor down the center of the foot wide cut. This must be uniform in width and depth and at least 6 pounds should be taken for every foot in thickness of the seam. There should go into the sample as cut everything which goes into the daily shipments of the coal and only such material should be discarded as is discarded by the ordinary miner. Usually partings more than $\frac{3}{8}$ inch in thickness and sulphur concretions or other impurities more than 2 inches in maximum diameter and $\frac{1}{2}$ inch thick are excluded if they are excluded by the miner or before shipping.

After cutting sample, weigh it with a spring balance, crush and screen until the whole sample passes through $\frac{1}{4}$ -inch screen. Mix by thoroughly rolling the sample on the canvas cloth, quarter, reject the two opposite quarters, and mix again. Quarter again if sample is still above 10 pounds; re-mix, and quarter again if necessary. Fill sample can compactly and completely. Use scoop from sampling kit and fill can by taking scoops across the whole of the sample as last quartered. Put label inside of can, screw cap on tightly, and seal with adhesive tape. The entire operation of sampling and mixing should be done inside of the mine. Where there is an unworked bench of coal 1 foot or more in thickness, three or more separate samples should be taken at convenient points of the unworked bench. Where coal is washed, duplicate samples of the washed coal and the tailings should be taken and forwarded with the mine samples. Take sectional measurements of the coal seam with reference to impurities, bands, etc.

Take set of Bureau of Mines notes (a, b, c, d, etc.).

In making out mine sample cards, locate the place of taking sample by distance and direction from opening as well as by room or entry number. Mail cards promptly.

^a This form is printed on loose-leaf sheets, size $3\frac{1}{2}$ by $6\frac{1}{2}$ inches, perforated at the left for binding.

FORM GIVING INSTRUCTIONS FOR ROAD AND RIB DUST SAMPLING.*

DEPARTMENT OF THE INTERIOR,

BUREAU OF MINES.

INSTRUCTIONS FOR ROAD AND RIB DUST SAMPLING.

Take 5 or 6 samples at various points in haulage roads between drift mouth or shaft and working places.

Take each road dust sample with standard scoop and brush over sections of road and rib 6 inches wide; loose road dust to be taken to a depth of not over 1 inch and road and rib samples to be kept separate. Each sample should be taken over a zone of 50 linear feet of entry; from 3 to 5 grooves should make up the sample. The scoop has a 10-mesh screen; oversize on this is rejected and the undersize placed on a sampling cloth. This undersize should be quartered and worked down to an amount sufficient to fill one sampling can; record should be kept of the weight of the gross sample and of the area from which it was obtained. Rib and roof samples should be gathered at the same points as the road dust samples are taken. The total area from which the rib sample is brushed should be recorded. A gross road sample on dusty roads of from 15 to 25 pounds should be obtained. The total amount of rib sample obtained may after screening only fill one can or less. When roadways are damp difficulty may be experienced in dust screening. In this case put all of road sample, except pieces $\frac{1}{2}$ inch or larger, which may be rejected by eye, on sampling cloth, mix thoroughly and quarter down to two cans as before, recording weight of gross sample and number of grooves the sample is taken from.

Ship samples properly taped in accordance with instructions for face samples. Mail descriptive cards (form 6-179) for samples promptly.

* This form is printed on loose-leaf sheets, size 3 by 6 $\frac{1}{2}$ inches, perforated at the left for binding.

FORM GIVING INSTRUCTIONS FOR MINE-AIR SAMPLING.^aMine Air
Sampling.

DEPARTMENT OF THE INTERIOR,

BUREAU OF MINES.

MINE-AIR SAMPLING.

BY

G. S. Rice, Chief Mining Engineer.

In its investigation of mine gases the bureau has adopted the "vacuum" and "aspiration" methods of sampling. For the information of men in the field, there follows a description of the precautions which should be observed in their use.

The gas laboratory will not analyze any sample that is not properly identified, therefore, sample cards (form 6-562) should always be completely filled out by the field man and forwarded with each sample. Especial care should be taken that each bottle is numbered and that the number is placed on the card in the space provided for that purpose.

In transmitting the samples to the laboratory special care must be taken to so pack them that they can not be shaken around in the box. Bottles placed loosely in the box are often broken when received at Pittsburgh.

A. VACUUM METHOD.—For sampling gases where the person taking the sample is in the gases being sampled, the *vacuum method* should be used. The vacuum bottle should be examined and, if found free from cracks, opened in the location where the sample is desired. By inserting the capillary tube at the end of the container through the eye of an ordinary key and bending slightly, a clean break at the file mark can be obtained. A distinct whistling sound should be heard as the gases rush into the bottle. The absence of such sound indicates a poor vacuum and necessitates another sample. When the bottle is full it should be sealed with the wax furnished by the Pittsburgh laboratory. The wax should be softened and worked into the opening for not less than one-quarter inch nor more than three-eighths inch, after which *all wax should be removed* from the outside of the glass. It may then easily be seen whether or not the sealing has been properly accomplished. A ball of wax simply placed over the end of the tube *will not retain the gas in the bulb*. The wax may be softened before going into the mine and, if carried in a sack or pocket under the outer clothing so it will be kept warm by the heat of the body, it will remain soft. In cold weather the samples should be taken to a warm place as soon as possible, and the seal examined; if necessary additional wax should be used to obtain the full one-quarter inch specified above.

B. INSPIRATION METHOD.—When a gas sample is desired from an area not accessible to the person taking it, and must be taken through a pipe or hole in a stopping, the *aspiration method* should be used. For this purpose are needed bottles similar to those used by druggists for holding magnesium citrate, an aspirating bulb, rubber tubing, and a piece of glass tubing or one-eighth inch metal pipe. These may be obtained from the Pittsburgh station when they can not be obtained locally. The bulb has a check valve in each end. As rubber deteriorates rapidly, in selecting a bulb and each time before using it, examine the valves to see if they are working properly, as their faulty operation would make the sample worthless and cause a loss of time, labor, and records of value. The small tube which is connected to the intake side of the bulb should be pushed through the stopping until it projects beyond the end of the pipe or the hole in the stopping. The tube should be so surrounded by packing that no air can be drawn in as it is pushed through the pipe. Another piece

^a This form is printed on loose-leaf sheets, size 3½ by 6½ inches, perforated at the left for binding.

of tubing connected to the pressure side of the bulb should be thrust into an open inverted bottle to within about one-quarter inch of the bottom. The bulb should then be repeatedly squeezed until all the air in the tubing, bulb, and bottle has been forced out by the incoming gases. Towards the end of the filling process, the mouth of the bottle should be nearly covered over with the hand or a cloth to prevent reentry of air. For a stopping pipe of one inch diameter and three feet long the bulb should be squeezed about one hundred times. The tube should then be *slowly* removed from the bottle, all the time continuing a *gentle* operation of the bulb. When the tube has been completely removed from the bottle the stopper should be quickly clamped in place.

If the sample is taken from a deep bore hole, unless "upcasting," additional pumping of the bulb may be necessary for displacement of the air from the longer tube. If downcasting strongly it is virtually impossible to take a sample representative of the atmosphere in the mine excavations.

When the gases being sampled are under pressure so that they rush out of the pipe, the bulb can be omitted from the connections and the gases allowed to flow through the bottle for about five minutes. Care should be taken to remove the tubing very slowly from the bottle. If the gases flow with considerable velocity it is advisable, in order to prevent eddy currents from drawing air into the bottle, to check the flow somewhat while taking out the tubing.

Where it is not convenient to connect the tubing directly to a hole from which gas is escaping, the large end of a funnel may be placed over the hole, plastering around the edges with mud. The tubing can then be connected to the small end of the funnel and the sample taken as above. This method is useful when taking a sample of gas from a "blow-hole."

If a mine stopping shows effects of intaking, such as the drawing in of air when the valve is open, or through leaks, it is of little use to take samples unless a long pipe is inserted into the area, and then the air should be drawn out of the sampling pipe by long continued pumping of the bulb. Even then the sample may be open to question, so, in general, it is best to sample only when there is either a condition of equilibrium or preferably a pressure on the inside.

It is important to note on the cards and accompanying report whether the air or gas being sampled was upcasting or returning, downcasting or intaking, or in equilibrium.

FORMS USED IN REPORTING COAL-MINE INVESTIGATIONS.^a

DEPARTMENT OF THE INTERIOR.

BUREAU OF MINES—COAL-MINING REPORT.

A.—PHYSICAL FEATURES.

- 1 Mine..... Investigator..... Date.....
- 2 State..... County..... Twp..... S..... T..... R.....
- 3 Mine location (distance and direction from nearest Ry. station).....
- 4
- 5 Mine Ry. connections.....
- 6 Operating company.....
- 7 Address.....
- 8 Address, mine.....
- 9 General manager.....
- 10 Superintendent.....
- 11 Mine foreman.....
- 12 Selling agent.....
- 13 Address.....
- 14 Trade name of coal.....
- 15 Number of beds worked..... Geologic series.....
- 16 Name of bed..... Thickness.....
- 17 Interval and kind of rock.....
- 18 Name of bed..... Thickness.....
- 19 Interval and kind of rock.....
- 20 Name of bed..... Thickness.....
- 21 Kind of coal in each bed.....
- 22 Dip of beds.....° Direction of dip.....
- 23 Cleat..... Direction of.....
- 24 Faults..... Frequent?.....
- 25 Rolls or horsebacks..... Frequent?.....
- 26 Methane.....from coal, roof, or floor.....
- 27 Quantity.....max. in return.....%
- 28 Entrance to mine: Drift, cross-drift, slope, shaft?.....
- 29 Elevation of entrance above sea..... Bar..... Actual.....
- 30 Vertical depth to landings (below entrance).....
- 31 Geologic section.....

(Make on an adjoining page a vertical cross section indicating position of coal beds and other strata with reference to surface.)

32 Remarks:.....

^a All forms of this group are printed on loose-leaf sheets, 4½ by 7½ inches, perforated at the top for binding.

DEPARTMENT OF THE INTERIOR.

BUREAU OF MINES—COAL-MINING REPORT.

B.—EQUIPMENT.

- 1 Mine..... Investigator..... Date.....
- 2 Capacity per day..... tons. Actual average..... tons.
- 3 Number of men underground..... Above.....
- 4 Steel or wood tippie.....
- 5 Cage, type.....
- 6 Hoisting or slope engine, type.....
- 7 Boilers, number..... horsepower, total.....
- 8 Electric generators, No. and type.....
- 9 Voltage..... Total capacity.....
- 10 Compressors, No..... Capacity..... Pressure.....
- 11 Fan, type..... Average water gage..... in.
- 12 How driven.....
- 13 Number of splits air.....
- 14 Miners' lamps, open or closed..... Kind.....
- 15 Oil used..... Smoky or bright.....
- 16 Lighting system or main roads..... Voltage.....
- 17 Mine water, gals. p. m..... Type and No. of pumps.....
- 18
- 19 Coal-cutting machines, type and number.....
- 20 No. of..... Voltage..... DC or AC.....
- 21 Haulage system.....
- 22 No. locomotives..... If electric, voltage.....
- 23 Mine cars, type..... Tight gate.....
- 24 Weight empty..... lbs. Capacity..... lbs. No. cars.....
- 25 Track gage..... Rail wt.: Entries..... Rooms.....
- 26 Ties, kind of wood..... Size.....
- 27 Props, kind of wood.....
- 28 Stoppings, kind: Main entries..... Side entries.....
- 29 Room mouth stoppings, if any.....
- 30 Remarks:.....
-
-
-

DEPARTMENT OF THE INTERIOR.
BUREAU OF MINES—COAL-MINING REPORT.

C.—STATION HUMIDITY (1).

Mine..... Investigator..... Date.....

1 Time of day when following observations made..... M.
2 Station.....
3 Distance from entrance or shaft..... ft.
4 Dry bulb.....°; wet bulb.....°; barometer..... in.
5 Depression ($t-t'$).....°; relative humidity..... %
6 Passage: Width.....ft.; height.....ft.; area.....sq. ft.
7 Velocity air per min.: Reading.....ft.; corrected.....ft.
8 Volume air per min..... cu. ft.
9 Intake or return.....
10 Number of men on split.....; number of mules.....
11 At station, is floor dry or moist?.....
12 At Station, are ribs dry or moist?.....
13 At station, is roof dry or moist?.....
14 Length of cap on lamp.....; lamp used.....
15 Method of sampling air.....; sample number.....

1 Time of day when following observations made..... M.
2 Station.....
3 Distance from entrance or shaft..... ft.
4 Dry bulb.....°; wet bulb.....°; barometer..... in.
5 Depression ($t-t'$).....°; relative humidity..... %
6 Passage: Width.....ft.; height.....ft.; area.....sq. ft.
7 Velocity air per min.: Reading.....ft.; corrected.....ft.
8 Volume air per min..... cu. ft.
9 Intake or return.....
10 Number of men on split.....; number of mules.....
11 At station, is floor dry or moist?.....
12 At station, are ribs dry or moist?.....
13 At station, is roof dry or moist?.....
14 Length of cap on lamp.....; lamp used.....
15 Method of sampling air..... Sample number.....
16 Remarks:

E.—EXPLOSIVES.

- Digitized by Google

DEPARTMENT OF THE INTERIOR,
BUREAU OF MINES—COAL-MINING REPORT.

F.—MINING CONDITIONS AND METHODS.

- 1 Mine Investigator Date
- 2 Name of coal bed
- 3 Range in thickness of workable coal
- 4 Impurity, variability, and character
- 5
- 6 Roof, kind and quality, thickness of draw slate or roof coal
- 7
- 8 How many lines of props in rooms? Distance between props
- 9 Do entries require timbering, extent?
- 10 Kind of timbering Distance between sets
- 11 Floor, kind, soft or hard
- 12 Surface, smooth or rough
- 13 Is coal cut or sheared? By machine?
- 14 Is cutting done in floor or coal?
- 15 Are machine cuttings loaded into cars? Before shooting?
- 16 Do pieces of roof or floor become mixed with coal?
- 17 System of mining (longwall, room and pillar, butt entries, panels, etc.)
- 18 Is mine laid out with reference to "butts" and "faces"?
- 19 Are rooms turned off air courses?
- 20 Distance between levels or cross entries
- 21 Entry width, main ft.; side entry ft.; stub ft.
- 22 Pillar width, main ft.; side entry ft.; stub ft.
- 23 Room pillar, width ft.; barrier pillar, width ft.
- 24 Room width ft.; room length ft.
- 25 Room pillars pulled? Entry pillars pulled?
- 26 Proportion of coal taken in advance work %
- 27 Per cent recovery, excluding roof coal %; including %
- 28 Approximately what unmined area is to be taken out from present opening? acres.
- 29 What is probable lifetime of mine?
- 30 In what proportions will tonnage be derived from advance work or pillars?
- 31 Present daily average output of mine tons (..... lba.).
- 32 Maximum day's run tons. Output for year
- 33 To what extent is daily output to be increased or diminished in future?
- 34 Remarks:

**DEPARTMENT OF THE INTERIOR,
BUREAU OF MINES—COAL-MINING REPORT.**

H.—SAMPLE SECTION.*

- 1 Mine Investigator Date
 2 State Can number
 3 County Township
 4 Name of bed of coal
 5 Location in mine
 6 Total (vertical) depth from surface at point of sampling..... ft.

In describing the beds and character of the members, note any member that is rejected by the miner. Note all clay and surface partings, whatever their thickness. Exclude from sample all clay and sulphur partings $\frac{1}{8}$ inch thick or over, and even those of less thickness if they are rejected at mine or tipple.

Section of bed at point sampled.

DESCRIPTION.		FEET.	INCHES.
7 Roof (main)			
8 Roof (immediate)			
a			
b			
c			
d			
e			
f			
g			
h			
i			
j			
k			
l			
m			
n			
Total			
9 Floor			

- 10 Is coal sample wet or dry?
 11 Time exposed hours, min.
 12 Weight gross, net.
 13 What are the impurities, and how do they occur?
 14 What impurities are shipped with the coal?
 15 What (X) are excluded from the sample?
 16 Remarks:

* Form G refers to preparation of coal for market and is omitted here.

**DEPARTMENT OF THE INTERIOR,
BUREAU OF MINES—COAL-MINING REPORT.**

K.—RESCUE APPARATUS AND FIRE-FIGHTING EQUIPMENT.*

1. Mine.....
Investigator..... Date.....
2. Number of breathing apparatus..... Name.....
3. Helmet or mouth-breathing type (H)..... M. B.....
4. Oxygen pump..... Name.....
5. Oxygen receiving devices..... Name.....
6. Number of regenerator charges in stock..... Oxygen tanks.....
7. Character and kind of training room or gallery.....
8.
9. Does this mine have access to joint rescue station?.....
10. Where is joint station located?..... Distance from mine.....
11. Is apparatus in good condition?.....
12. Who is in charge of apparatus?.....
His title.....
13. Is it regularly tested?..... Is a record of tests made?.....
14. How many men have been trained?.....
15. Are men trained regularly and how often?.....
16. Is a rescue crew maintained?.....
17. Are refuge chambers maintained in any part of mine?.....
18. How many chambers?..... Location.....
19. How far from working places?..... From mine opening?.....
20. Give dimensions (also sketch on another sheet).....
21. Is there a drill hole to chamber?..... Telephone or other signal?.....
22. How is chamber ventilated?.....
23. What supplies, tools, etc., are kept in chamber?.....
24.
25. Are miners instructed how to reach chambers?.....
26. Is there an underground hospital?..... Equipment.....
27.
28. Are any first-aid packages and stretchers kept underground?.....
29. Are fire drills practiced in mine?.....
30. How often do the miners practice?.....
31. Are there fire protection pipe lines throughout mine?..... Diam. pipes.....
32. Pressure of water in pipes in mine..... Frequency of water taps.....
33. Is hose kept at station underground?..... How many stations?.....
34. Length and diameter of hose?.....
35. Is water always available?..... Are water barrels and pails provided?.....
36. Remarks:

* Forms I and J are not pertinent to this bulletin and are omitted.

DEPARTMENT OF THE INTERIOR,
BUREAU OF MINES.

OUTLINE.

REPORT OF THE EXPLOSION HAZARD OF AND EXPERIMENTAL MINE TESTS OF COAL
FROM .. MINE OF THE COMPANY AT

PAGE.

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Floor.....	
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General.....	
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Ignition tests.....	
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Tests with pulverized coal dust.....	
Ignition tests.....	
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Watering.....	
Rock dusting.....	
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Quantity necessary.....	
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Rock-dust barriers.....	
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Summary and recommendations.....	

PART 2.—TYPICAL INSTRUMENT-RECORD CURVE SHEETS OF EXPLOSION TESTS AT EXPERIMENTAL MINE.

The first instruments used at the experimental mine were similar to those used in testing in experimental galleries in foreign countries. These were described in Bulletin 56 of the Bureau of Mines. It was soon discovered that they would not be suitable for work in the mine, and the development of new instruments began. This development is still proceeding and will probably continue as long as the explosion tests are being made. The development to date has been described in Bulletin 56 and in Chapter II of this bulletin.

The records obtained have but small value when considered separately. To yield the maximum information, they must be considered in groups, all of the records for any one test being plotted together on one sheet of cross-section paper. These curves have been described on page 57, where the curve for test 301 is considered in detail to illustrate the method of plotting. The description of methods of calculating and plotting will not be repeated here. It is the intention to give in this section a number of curve sheets of typical tests and a brief analysis of the results indicated by each curve.

One of the problems in plotting was the choice of suitable symbols for representing the various instruments. These symbols were devised as they were needed in the development of the plotting methods. At the time of writing they have been standardized to some extent and a list of them is given herewith. The symbols may be divided into two classes: First, those used in the loading diagram to the left of the axis of ordinates; second, those used in the instrument record diagram to the right of the axis of ordinates. The list of symbols here given includes all those used in the curve sheets in this bulletin. Those used in test 301 have been given on the curve sheet listed as figure 3.

LIST OF SYMBOLS USED IN INSTRUMENT-RECORD CURVE SHEETS.

In Figure 53 *a* are shown symbols used on the curve diagrams of the different tests, shown on preceding and following figures. Symbols *a* to *g* appear on the various figures to the left of the ordinates and indicate the loading in different zones, the origin, and the rock dust barrier devices used in the respective tests. Symbols *r* to *t* are points of location of different devices on the curves used in the respective tests. The symbols are defined as follows:

- a*, hatching, single diagonal lines, indicates zone loading of pulverized Pittsburgh coal dust.
- b*, hatching, double diagonal lines, indicates zone loading with coal dust other than Pittsburgh pulverized dust, the kind specified in the label.

- c*, small crosses between diagonal patched lines indicate inert dust such as shale or limestone dust.
- d*, small circles superposed on hatching, indicates fire damp or methane in the air current, the percentage, also the dust loading being specified in the label.
- e*, hatching, diagonal dashes, indicates water in the mixture.

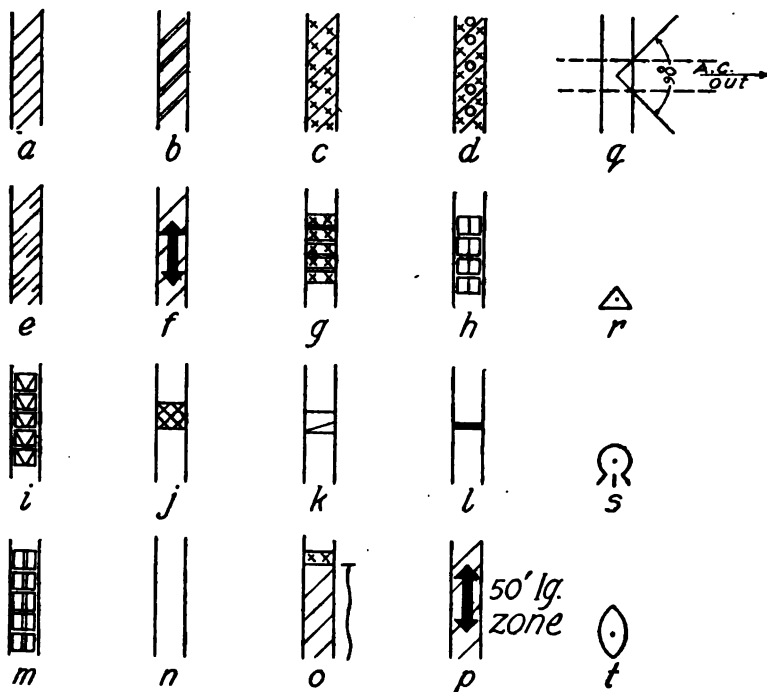


FIGURE 52a.—Symbols used on the graphs illustrating the tests: *a*, loading with Pittsburgh coal dust; *b*, loading with other coal dust; *c*, inert dust; *d*, methane in air current; *e*, water in dust mixture; *f*, location of cannon or origin of explosion; *g*, Taffanel barrier; *h*, box barriers; *i*, V-trough barrier; *j*, concentrated barrier; *k*, ventilating-door barrier; *l*, rock-dust stopping; *m*, trough barrier; *n*, no dust loading; *o*, travel of explosion flame; *p*, ignition zone; *q*, representation of 90° turn; *r*, starting and ending point of movement; *s*, dust barrier operated; *t*, gas sampler.

- f*, a blunt arrow indicates location of shot-firing cannon or origin of explosion; a double-pointed arrow shows where the explosion travels in two directions; when the explosion has two branches (entry and air course) the diagram is plotted to represent each branch as a separate explosion above and below the axis of the flame velocity curves, which axis, if projected, intersects the middle of the double-pointed arrow on the loading diagram.
- g*, symbol for (Taffanel) dust-shelf barrier, hanging shelves, and modification thereof; the particular kind of open shelf, the number of shelves, and kind of rock dust used are given in the label.
- h*, symbol for (Rice) box barriers, the kind, the number of boxes in a unit, and kind of rock or inert dust used are given in the label.

- i*, symbol for V-trough barrier; the number of troughs and the kind of rock dust used are given in the label.
- j*, symbol for (Rice) concentrated barrier; the type of barrier and the kind of dust are given in the label.
- k*, symbol for (Rice) ventilating-door barrier; the kind of dust used is given in the label.
- l*, symbol for (Rice) rock dust stopping; the kind of rock dust used is given in the label.
- m*, symbol for (Rice) trough barrier; the number of troughs and kind of inert dust is given in label.
- n*, no marking between lines showing sides of passageway indicates no loading, or dustless condition.
- o*, the wavy line along line of passageway indicates where flame traversed the passageway or the length of travel of the explosion flame; limits being determined by melting of station foils, and records on photographic paper placed in pipe fittings projecting from the roof. In the tests before test 226, the determinations between stations were made by the burning or nonburning of match heads and guncotton.
- p*, the label "50 Ig. zone" beside *f* means that at the origin of a propagation test there was adjacent to the cannon a 50-foot zone of pulverized Pittsburgh dust, the standard ignition zone for a "propagation" test.
- q*, indicates, when shown on the diagram of the entries, that the representation of one of two intersecting entries has been swung through 90° so as to bring the apparent path of the explosion in a straight line from the point of origin, to enable a direct comparison to be made of flame velocities, etc. As the mine passages are in pairs there are always two paths for the explosion waves from the origin to the two exits. In the diagrams of tests, except the earlier single-entry tests, the curves of both paths are shown, one above the horizontal axis line of each diagram, the other below the axis line.
- r*, marks the starting and ending point of the movement of the so-called "trolley" used to measure air or gas velocity independent of the true explosion wave; it is placed on the diagram with reference to ordinates (vertical) of distance from origin of the explosion and to ordinates (horizontal) of time.
- s*, operation of dust barrier operation, is placed on the graph with reference to distance from the origin of the explosion and to recorded time of operation, i. e., dumping of rock dust.
- t*, automatic gas sampler, the length of the oval when placed horizontally on the base line of the station curve (parallel to the axis) indicates the relative time of taking the sample, between the opening and closing of the sampler. The adjacent number is the laboratory number of the analysis.

ADDITIONAL SYMBOLS.

The small circles on or adjacent to the monometric curves indicate the time of burning or rupture of the foil by the explosion flame at the respective station. The curve drawn through or near by these points is labeled "foils," and from it the flame velocity at any point of the explosion can be figured within certain rather wide limits of error.

T Indicates the time of operation of a coke trap at A 1161, closing inby.

E 750 B. C. D. Record of British coal-dust manometer at E 750.

E 950 B. M. Record of Bureau of Mines manometer at E 950.

A 750 F. Record of French manometer at A 750.

Each manometric curve is plotted above the base line drawn horizontally through the respective station.

The broad line or area under the base line of a manometer curve, usually at the time of rupture of the tin-foil at that station, indicates flame photographed by the manometer, its length showing the duration of the flame at that point. The width of the area, which is similar to that of the photograph on the manometric sensitized paper, indicates roughly the intensity of the flame. This is labeled "Flame."

E 1150. The number of a station located just to the right or left of the axis of ordinates indicates its location with reference to the cannon in the particular test.

A 950 Air Motion. Record of air-direction indicator at A 950.

The direction of the air is indicated by the position of a parallel line above or below the base line through the respective stations; when the direction shifts a diagonal line terminating a parallel line above the base connects to a parallel line below the base, or vice versa. The length of the parallel line indicates by the time ordinates the interval of time the air is moving in the indicated direction, toward the origin or away from it.

GENERAL NOTE.—Symbols or legends made up of two parts, as the last, "A 950 Air Motion," may vary. Thus the station of the air-motion indicator may be any one, depending on the location of the instrument, as "E 750 Air Motion," "1 B 50 Air Motion," etc.

Pressures.

-1.2 lb. at 5.8 sec.
0.0 lb. at 7.3 sec.
+0.8 lb. at 9.1 sec.
0.0 lb. at 9.3 sec.

Manometer records are obtained for 10 seconds after the firing of the cannon, provided the pressure varies that long. It is usually inadvisable to plot these records beyond four to six seconds because of the excessive length of the resultant plotted curve

and the small value of the pressure beyond six seconds in most tests. The maximum pressures, maximum suction, and zero points of the manometer curves after the time selected as the end of plotting are inserted as a table at the end of the plotted manometer curve.

Air motion.

Off at 5.71 sec.
 Face at 6.17 sec.
 Off at 7.02 sec.
 Mouth at 7.98 sec.
 Off at 9.19 sec.

The air-direction indicator results are obtained until the air velocity falls below 50 feet per second, provided this occurs in less than 15 seconds, as it usually does. Values after the time selected as the end of the plotted manometer curves are tabulated and placed at the end of the curve in the form here given. The words "Off," "Face," and "Mouth" indicate that the instrument ceased movement, recorded toward the face of the entry, and recorded toward the mouth of the entry, respectively. In every test the instrument remained in the indicated position until the time of the next record given.

DISCUSSION OF TYPICAL INSTRUMENT-RECORD CURVE SHEETS.

Seven instrument-record curve sheets have been placed in this bulletin previously in connection with the results of tests. These are mentioned briefly at this point, and a series prepared to show the results obtained with various arrangements of loading will be discussed in some detail.

CURVES PREVIOUSLY GIVEN.**FIGURE 3, TEST 301.**

The curve records a standard propagation test of medium strength. The explosion development was rapid, the mixed dust igniting immediately from the burning pulverized Pittsburgh coal dust. Some of the more important points to note (see p. 57) are the intense flame record obtained on the E 1150 manometer; the rapid rise of pressure at A 950 and the equally rapid fall after the flame was extinguished, the maximum suction at A 1150 amounting to nearly 8 pounds; the reduction of the maximum pressure from A 950 to A 750 due to the operation of the barrier, and the series of pressure and rarefaction waves beginning on the A 950 manometer at about 1.5 seconds and continuing to about 10 seconds. These can be traced on all four manometers in the explosion zone.

FIGURE 14, TEST 44.

The curve was made in a test of an 800-foot single-entry zone of pure pulverized Pittsburgh coal dust. A very violent explosion with high flame velocities resulted. The pressure at E 550 was 119 pounds and occurred at the beginning of the record. It should be noted that while the maximum pressure was 119 pounds the pressure remained above 50 pounds only 0.08 second and above 10 pounds 0.3 second. This test has been discussed previously on page 82.

FIGURES 10, 15, 16, 11, AND 17, TESTS 105, 109, 113, 115, AND 138.

These curves were recorded in double-entry zone tests of pulverized Pittsburgh coal dust and have been discussed at some length on page 84; however, the following additional points should be noted:

In test 105 (see fig. 10, p. 74) the maximum pressures at each station except E 750 occurred after the flame had passed. The pressure at E 1150 at the time of passage of flame was 12 to 13 pounds, but the maximum pressure was 34 pounds. If allowance is made for the extra length of the cut-through in the air course branch, the two tin-foil curves are symmetrical.

In test 109 (see fig. 15, p. 87), the tin-foil curves show much lower velocities than in test 105. In test 113 (see fig. 16, p. 88), the tin-foil curves in the two entries are again symmetrical.

In test 115 (see fig. 11, p. 75), the point of ignition was in the stub entry off the 1250 cut-through. The shock-wave records at E 1150 and A 1150 have much the same form because of the symmetrical arrangement of the entries. A wave reflected from the face of the entry is recorded on each manometer 0.1 second after the first wave. The pressures rise very rapidly, indicating a fast moving explosion. After the flame was extinguished at A 950 a return pressure wave was registered at A 1150 at about 0.94 second, and probably added to the pressures at E 1150 and E 950 at 1.0 and 1.3 seconds, respectively. Similarly, from the high-pressure peak of E 950, at 0.89 second, a return wave or retonation wave added to the pressure of station E 1150 at 1.0 second, and reached Station A 950 at 1.24 seconds.

In test 138 (see fig. 17, p. 90), a violent explosion occurred. The pressures at E 950 and A 950 rose very rapidly and fell as rapidly after the explosion was extinguished. Retonation waves are recorded at E 1150 and A 1150.

CURVES OF VARIOUS TYPES OF EXPLOSIONS.

There are given in this section 26 curves typical of the different explosion tests which have been made in the experimental mine. These may be grouped as follows:

1. Single-entry zone tests of various lengths, including tests of dustless zones and rock-dust zones.
 2. Ignition tests with pure coal dust from various seams.
 3. Ignition tests with mixed dust.
 4. Propagation tests with mixed dust.
 5. Various special tests.
- A discussion of these tests follows.

GROUP 1.—SINGLE ENTRY ZONE TESTS.

There are six tests given in this group. All were with pulverized Pittsburgh coal dust. These tests are:

Test 198, 50-foot zone, without gas, dustless zone outby.

Test 199, 50-foot zone, 2.7 per cent gas, dustless zone outby.

Test 81, 100-foot zone, no gas, dustless zone outby.

Test 55, 600-foot zone, terminated by a barrier.

Test 84, 300-foot zone, shale dust zone outby.

Test 91, 300-foot zone, limestone dust zone outby.

Test 198—Figure 53.—This test, discussed on page 172, was one of a number of tests made to determine the length of flame from a standard ignition zone with no gas present. The flame traveled 85 feet down the entry or 35 feet beyond the end of the dust zone. It will be observed that a French manometer at E 1150 recorded first the shock wave, then at 0.24 second a wave reflected from the face of the air course and finally at 0.32 second a pressure wave of 4 pounds from the burning coal dust. The pressure fell below atmospheric after the flame was extinguished, a series of pressure and rarefaction waves being registered until the pressure of the gases had returned to equilibrium with the outside air. A French manometer at E 950 gave a similar record, the pressures being much smaller. A French manometer at A 1150 gave corresponding records. B. C. D. manometers at E 750, A 950, and A 750 were not affected. The air direction indicator at E 950 was out of order and recorded only air currents moving inward. It should be noted that the indicators gave no record of air moving inward until after the flame was extinguished. This test indicates that the effect of the ignition zone in a propagation test does not extend much over 0.6 second. Pressures after this time or flame extension more than 35 feet beyond the ignition zone are caused by the burning of the dust outby the ignition zone.

Test 199—Figure 54.—This test, discussed on page 176, was identical with test 198, except that there was, in addition, 2.7 per cent gas in the air current. The effect of this gas is evident in the curve. The flame has been extended an additional 50 feet by the gas; the pressures are higher and more sustained. It should be noted, however, that again no record was obtained on B. C. D. manometers at E 750, A 950, and A 750. The air direction indicators at E 950 and A 950 indicated outward movement of the air beginning at 0.29 and 0.35 second, respectively, and continuing until after the flame was extinguished. These records start 0.02 second and 0.03 second after the arrival of the shock wave at the two respective stations. During this small interval of time the instruments are turning through the small angle necessary to make the electrical contact on the back of the instrument. Examination of a large

number of curves has shown that the time of first contact of the air direction indicators depends solely on their distance from the cannon; the first movement is always away from the shot and is caused by the shock wave. In test 199 the outward rush was followed, after

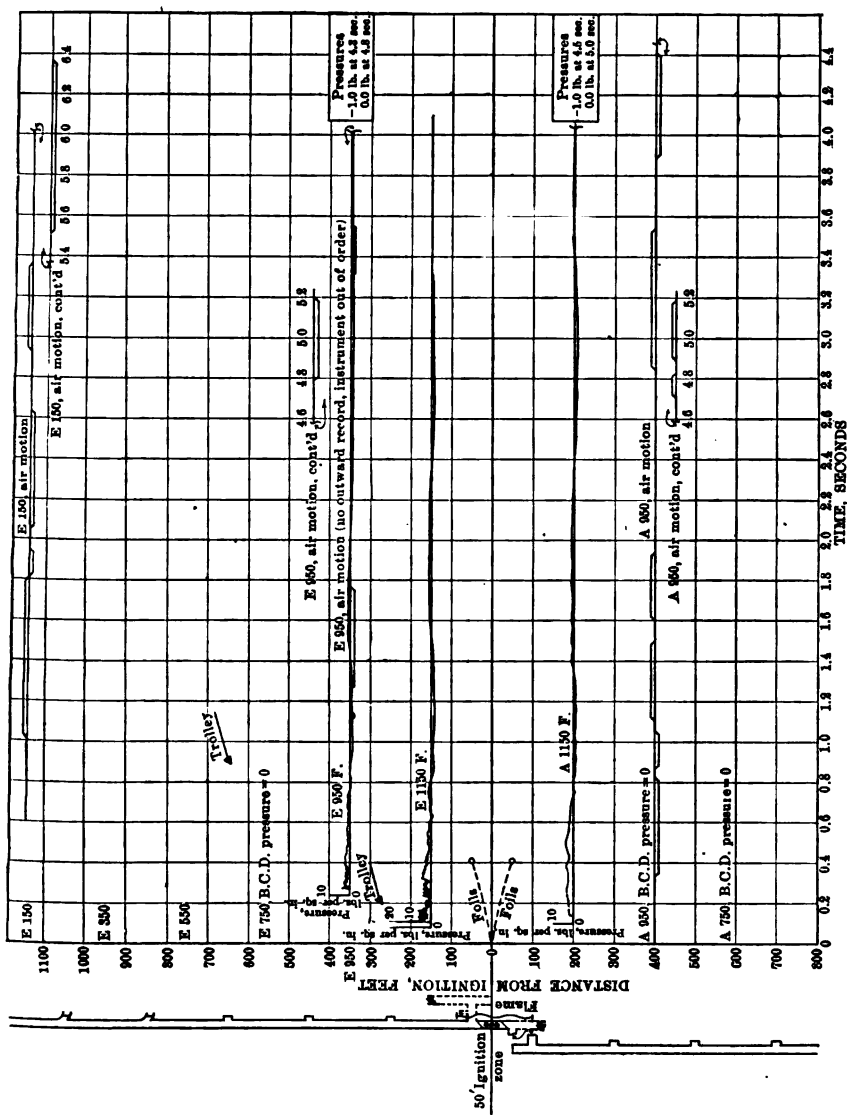


FIGURE 53.—Curve showing result of single-entry zone test with pulverized Pittsburgh coal dust (No. 198) to determine the length of flame from a standard 50-foot ignition zone with no gas present and with dustless zone outby.

the flame was extinguished, by an inward rush to fill the partial vacuum caused by the cooling gases. The vibrations back and forth continued until equilibrium was established. This test shows that the effect of the ignition zone is extended by the presence of gas.

The curve sheet indicates that in a test having 2 per cent or more of gas in the ventilating current, the effect of the ignition zone will be manifest for 0.8 second, pressures after this time or flame extension more than 85 feet beyond the ignition zone being due to the burning of the dust outby the ignition zone.

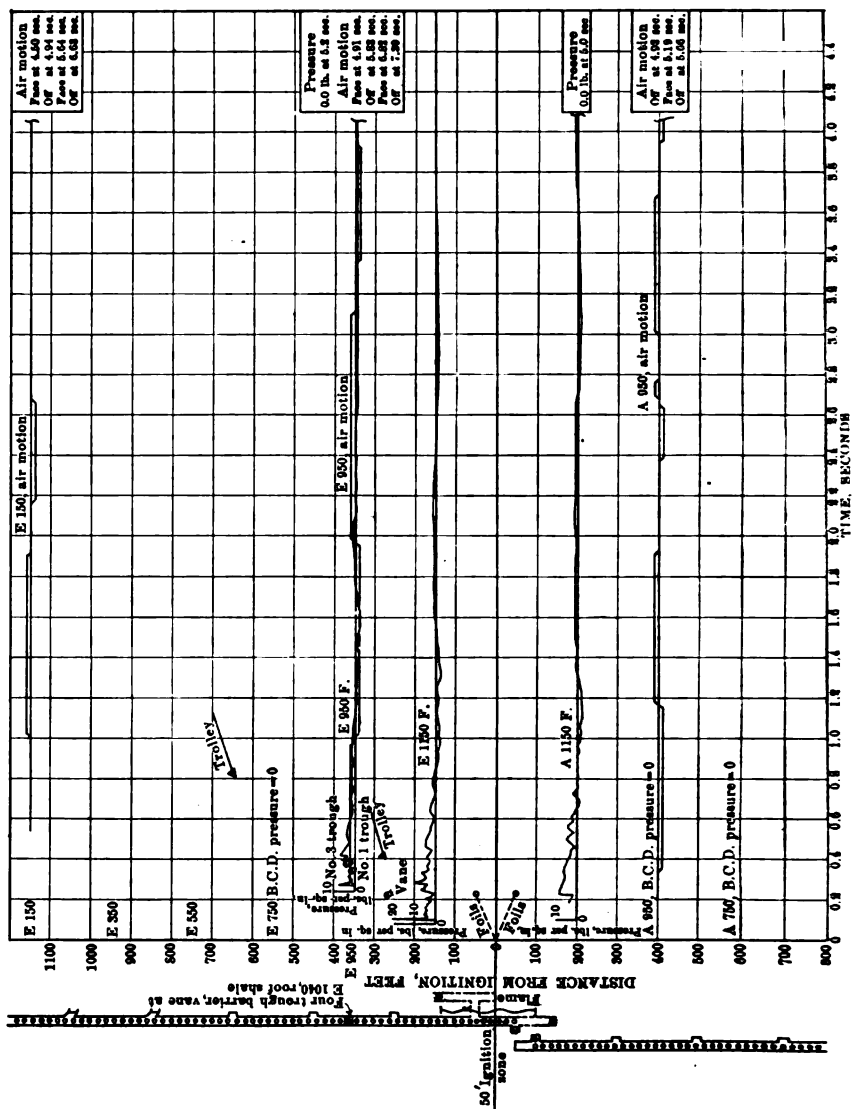


FIGURE 64.—Curve showing result of single-entry zone test (No. 100) to determine the length of flame from a standard 50-foot ignition source with 2.7 per cent gas in the air current and with dustless zone outby.

Both tests 198 and 199 were made after the entry was concrete lined and cleaning out by the dust zone was thoroughly done. In an entry not so lined the flame extension would have been much greater, as described on the following page.

Test 81—Figure 55.—This test, discussed on page 72, was a dustless zone test before the entries were concreted. Pulverized Pittsburgh coal dust was loaded from E 1300 to E 1200 and A 1250. A 500-foot "dustless zone" was prepared outby the coal dust in the entry. The flame swept through this and 200 feet outby a Taffanel barrier, which terminated the zone. The curve shows that a pressure wave traveled ahead of the flame, operating the pressure circuit breakers. The flame continued with increasing velocity for 250 feet outby the end of the coal-dust zone, after which its velocity decreased, at first for lack of fuel and later because of the quenching action of the stone dust of the barrier. It should be noted that the flame was accompanied by very little pressure after passing E 950. The pressure at

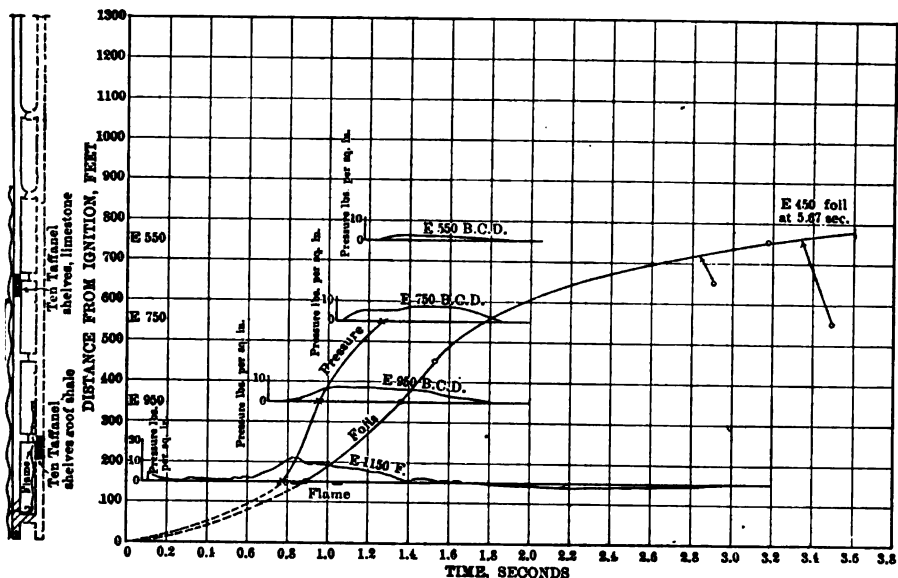


FIGURE 55.—Curve showing results of single-entry zone test (No. 81) made with a "dustless" zone 500 feet long, outby a 100-foot initiating zone of Pittsburgh coal dust, with no gas present.

E 1150 was due to burning dust until after the flame passed; then the pressure fell irregularly to zero. At E 950 the first part of the pressure record, including the maximum pressure, was caused by pressure waves traveling ahead of the flame through the gases with the velocity of sound. The pressure at E 950 was only 6 pounds when the flame passed, as compared with 12 pounds at E 1150. The pressure record at E 750 is almost entirely due to pressure waves preceding the flame and that at E 550 is entirely due to these waves. No pressure was recorded at E 550 at the time of passage of flame. The curve shows that, while the "dustless zone" caused a decrease in pressure and the velocity of the flame, any zone, to actually extinguish the flame, would have to be of such length and absolute cleanliness as to be entirely impracticable in an operating mine

Test 55—Figure 56.—This test, discussed on page 103, was a 600-foot single-entry zone test, the zone being terminated by a Taffanel barrier. This loading gave a violent explosion. A pressure wave preceding the flame wave operated the pressure circuit breaker. It is noticeable that after passing E 1150 the flame velocity becomes greater than the pressure wave velocity and the curves cross near E 750. The pressure circuit breakers were set for a pressure of 5 pounds and the manometer curves show that there was considerable lag in their operation outby E 950. Subsequently it was decided that, because of the lag of the circuit breakers, and other factors, the

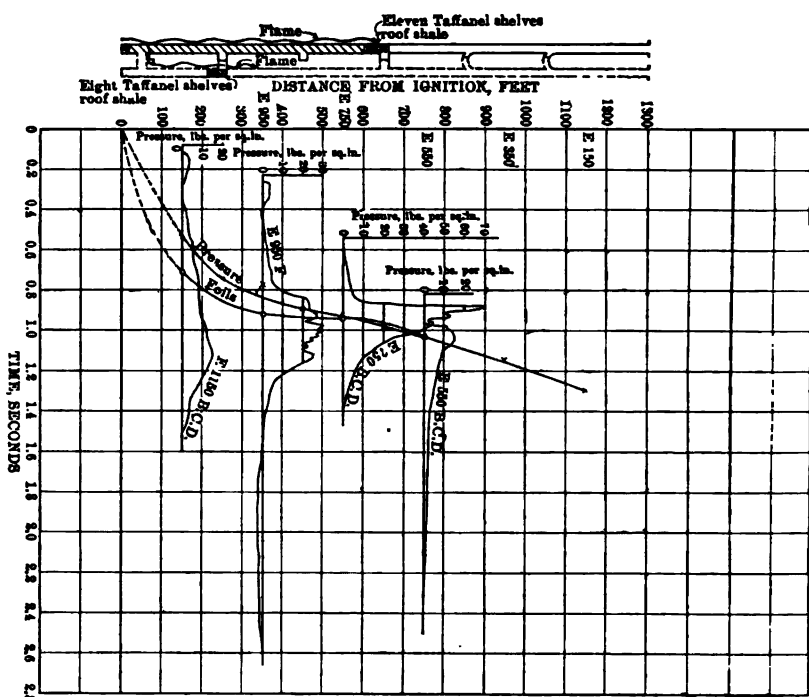


FIGURE 56.—Curve showing results of test (No. 55) with pulverized Pittsburgh coal dust in a 600-foot single-entry zone terminated by a Taffanel barrier.

velocity pressure curve was of little or no value. The maximum pressures at E 950 and E 1150 occurred after the passage of the flame and were caused by retonation waves. The maximum pressure at E 750 occurs slightly in advance of the foil record and was due directly to the combustion of the coal dust. The barrier checked the explosion, and the maximum pressure dropped from 71 pounds at E 750 to 15 pounds at E 550. The pressures at E 150 and E 350 were at least 5 pounds, since the pressure circuit breakers operated.

The curve of this test shows the steady increase in pressure and velocity obtained with pure coal dust. Higher pressures would have

been obtained had the zone been longer, but there is considerable question as to what the maximum velocity could be. If the flame in this case could have proceeded with the velocity indicated between E 950 and E 750, it would have overtaken the shock wave before reaching the pit mouth. This possibility has been indicated in a number of violent tests, but owing to the short length of the dust zones used it has never occurred. What would happen in a case of that kind is purely a matter of conjecture.

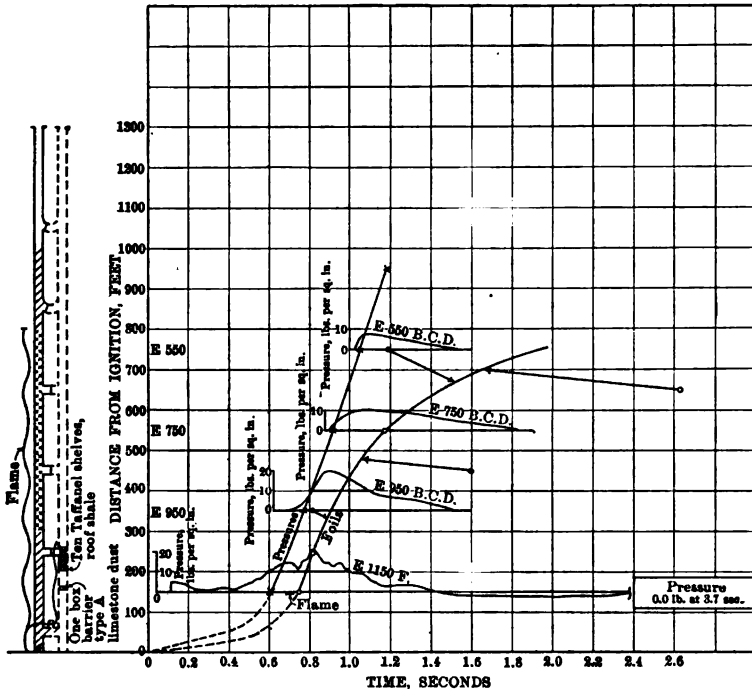


FIGURE 57.—Curve showing results of test (No. 84) of 500-foot rock-dust zone in which roof shale dust at 3 pounds per foot was placed on side shelves to determine its efficiency in extinguishing an explosion started in 300-foot zone of pulverized Pittsburgh coal dust, loaded at 2 pounds per foot.

Tests 84 and 91—Figures 57 and 58.—These tests, discussed on page 414 and following, were single-entry tests on rock-dust zones, rock dust being distributed outby 300-foot ignition zones of pulverized Pittsburgh coal dust. The tests differ in that shale dust was used in test 84, while limestone dust was used in test 91. Nevertheless the explosion development differed considerably in the two tests, this being a common occurrence with single-entry zone tests. This is shown by the fact that the pressure at E 950, 50 feet from the end of the coal dust zone, was 20 pounds in test 84 and 49 pounds in test 91, both pressures being ahead of the foil records. This could not be due solely to the difference in the rock dust. The flame traversed the zone in the second test more rapidly and extended a greater length.

Part of this is probably due to the higher initial pressures in the second test. The pressures and flame velocities decreased in both tests as the flame traversed the rock-dust zone. It is evident that all the tin-foil ruptures in test 84 were not caused by the flame. The curve as drawn is considered the most probable of several that could be drawn. The foils at E 950 and E 550 were evidently torn out by violence ahead of the flame. A curve through the E 850 and E 650 foils or the E 750 and E 650 foils would have sharp breaks that are not probable. The shape of the tin-foil curve in test 91 has influenced the drawing of the curve for test 84. In both tests 84 and 91, the

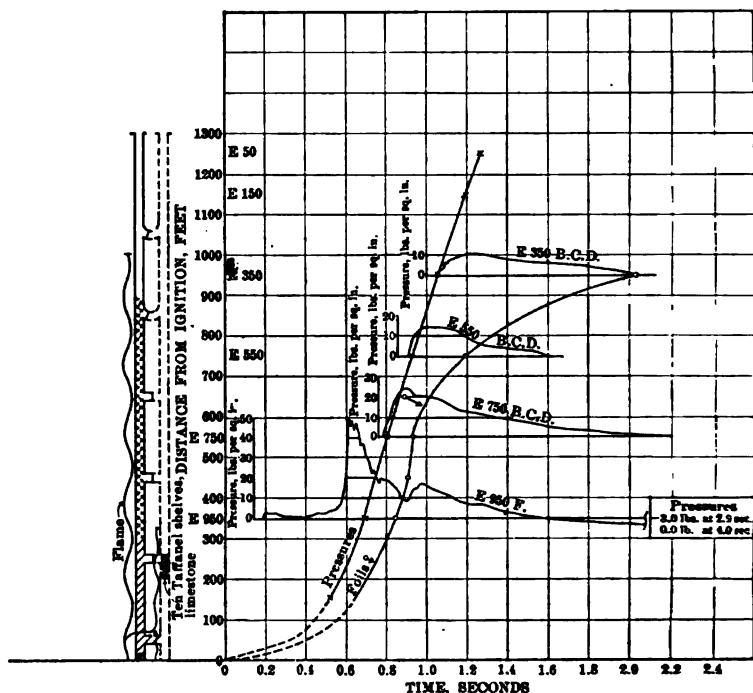


FIGURE 58.—Curve showing results of test (No. 91) of 600-foot rock-dust zone in which 5 pounds per foot limestone dust was placed on side shelves to determine its efficiency in extinguishing an explosion started in a 300-foot zone of pulverized Pittsburgh coal dust, loaded at 2 pounds per linear foot.

maximum pressures at E 950, E 750, and E 550 were caused by pressure waves ahead of foil fusion ^{4b}. There is a steady decrease in pressure through the rock-dust zone in both cases.

Comparison of the curves shows that the rock-dust zone had a quenching effect on the explosion in both cases, flame velocity and pressure decreasing through the zone. The shale was apparently more effective, but this difference is probably partly due to the explosions not being similar when entering the rock-dust zone. A comparison of these curves with tests of regular rock-dust zones will show that the method of throwing the rock dust on all surfaces is more efficient than placing it on the side shelves and the floor.

^{4b} The flame in the center of the entry was probably in advance.

GROUP 2.—IGNITION TESTS WITH PURE COAL DUST FROM DIFFERENT SEAMS.

This group comprises four tests showing the explosions developed in pure coal dust of different compositions and sizes. These are:

Test 262, pulverized Pittsburgh coal dust, light loading.

Test 347, 20-mesh (20 per cent 200-mesh) B or Miller seam coal dust.

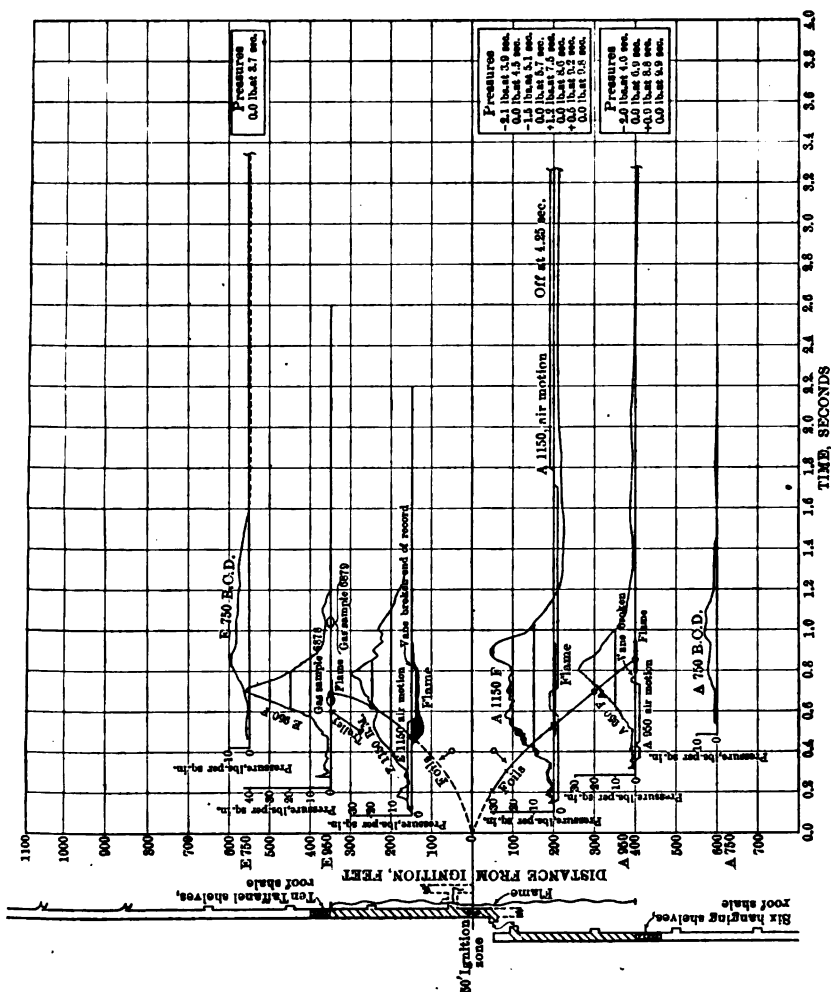


FIGURE 59.—Curve showing results of propagation test (No. 262) to determine the possibility of an explosion propagating through 100 per cent pulverized Pittsburgh coal loaded at the rate of 0.3 pound per linear foot of entry, with no gas present.

Test 358, 20-mesh (10 per cent 200-mesh) E or Upper Freeport seam coal dust.

Test 189, pulverized Lower Kittanning seam coal dust.

Test 262—Figure 59.—This test, discussed on page 94, was a propagation test to determine the possibility of an explosion propagating through pulverized Pittsburgh coal dust loaded at the rate of 0.3

pound per linear foot of entry. A very strong and rapid explosion resulted. The tin-foil curve in the entry shows increasing velocity through the zone; that in the air course shows nearly constant velocity. The manometer records at both E 1150 and A 1150 show a rapid rise of pressure due to pressure waves preceding the flame. After the front of the flame passed there was a slight fall in pressure, followed by a rise to the maximum, due to retonation waves. The maximum pressures at both E 950 and A 950 were caused directly by the explosion wave and the pressure fell immediately, the explosion being extinguished by the barriers. Two retonation waves traveling against each other are distinguishable; the first, starting with the maximum pressure at E 950 at 0.71 second, affected the E 1150 manometer at 0.78 second, and went through the cut-through into the air course, reaching A 1150 at 0.89 second. It was met at this point by a retonation wave traveling inby from A 950, the two combining to give a sudden rise in pressure of 10 pounds. The pressure wave traveling outby is not distinguishable on the A 950 manometer curve, but the one traveling inby passed into the entry recording at E 1150 at 1 second, at E 950 at 1.09 seconds, and possibly at E 750 at 1.18 seconds. It is interesting to note that the flame record on the E 1150 manometer continued after the flame was extinguished at E 950. After the flame was extinguished at A 950 a return pressure wave from the butt entries were recorded at A 950 at 1.6 seconds.

Two gas samples were obtained, one in the fore part of the flame, the other after the flame was extinguished.

The air direction indicator at E 1150 showed an outward movement of air from the shock wave until after the front of the flame passed E 1150, after which the point of highest pressure was outby E 1150 and the air at E 1150 reversed its motion. The vane of the indicator was hit by flying fragments and broken, ending the record. The air direction indicator at A 1150 recorded gases moving outby from the shock wave until after the front of the flame passed, then a short inward record followed by a longer outward record, the pressure inby A 1150 forcing the gases outward. The combined effect of this movement and cooling reduced the pressure below that of normal atmospheric pressure and the movement was reversed at 1.8 seconds, continuing in this reversed direction for 2.65 seconds. The movement may have continued for a longer period, but if it did the velocity was below that necessary to give a record. The A 950 air direction indicator was broken by flying débris. The inward record, lasting 0.01 second, was probably a false record caused by the breaking of the instrument.

This test shows the pressures and velocities which can be developed by the explosion of a very small amount of coal dust. This, with the

evidence given by test 81 (fig. 55, see p. 511) on a "dustless" zone, shows that an attempt to make a mine safe by making it dustless will meet with failure.

Test 347—Figure 60.—This test, mentioned on page 129, was a standard ignition test on pure 20-mesh B or Miller seam coal dust, of

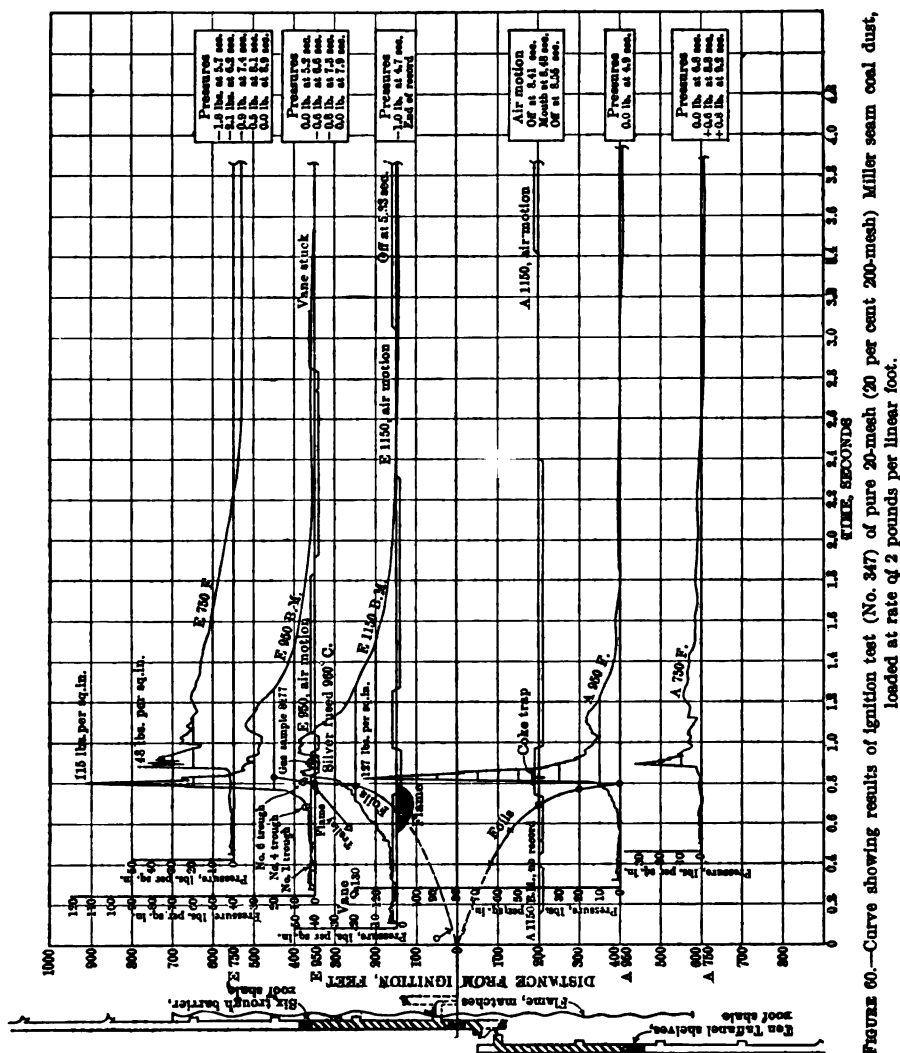


FIGURE 60.—Curve showing results of ignition test (No. 347) of pure 20-mesh (20 per cent 200-mesh) Miller seam coal dust, loaded at rate of 2 pounds per linear foot.

which 20 per cent would pass 200-mesh. A very violent explosion resulted, the pressure at A 950 (127 pounds) being the highest ever actually recorded. It will be seen that the explosion developed rapidly and attained high velocities in the last 100 feet. The flame traversed the distance from the cannon to E 950 and A 950 in 0.8

second. This time is unusually small for the distance. The flame record at E 1150 is noteworthy for its intensity. While the highest pressure at E 1150 was 49 pounds, the pressure at the beginning of the flame record was only 6 pounds and at the end of the flame record 29 pounds. The remainder was due entirely to retonation. The records at E 950 and A 950 show very little pressure ahead of the arrival of the flame, then the pressure rose abruptly to the maximum and fell again very rapidly. It should be noted that while the maximum pressure was 127 pounds the pressure was above 100 pounds for 0.02 second, above 50 pounds for 0.06 second, and above 20 pounds for a little over 0.12 second. This is very similar to a blow from a hammer. The manometer at E 750 recorded a number of waves from the burning coal dust inby; the manometers at A 950 and A 750 show a return pressure wave from the butt entries at 1.1 seconds, this being after the flame was extinguished.

One gas sample was obtained shortly after the passage of the flame. The composition of this sample was remarkable, there being a total of 22 per cent of combustible gas (methane, carbon monoxide, and hydrogen) present, the oxygen being less than 1 per cent. This would indicate a very high temperature and distillation from the coal. The silver foil was fused, the only time in entry testing that this occurred.

The air direction indicators at E 1150, E 950, and A 1150 showed outward movement of gas until the arrival of the flame at the respective stations. The direction at E 1150 and A 1150 reversed upon passage of the flame, the gases flowing back from the point of highest pressure at the flame to some point of lower pressure inby. At E 950 there were four reversals in rapid succession after the arrival of the flame, ending with the gas moving outward at 1.05 seconds. The gas was also moving outward past E 1150 and A 1150. The flame now being extinguished, this indicated a point of high pressure somewhere between E 1150 and A 1150, from which gas was flowing in both directions. This point moved out the entry, the E 1150 air direction indicator reversing at 1.27 seconds when it passed the station; the E 950 instrument also reversing at about 1.9 seconds when the point of high pressure moved outby that station. There is, then, for a short time a column of gas moving in the entry past E 950 and E 1150 and out the air course. Results of tests with the instruments in different locations show that this column of gas divides at the butt entries, some going on out the air course while some, and apparently the larger share, goes into the rooms. The gases in the entry and air course are continually cooling and contracting and the pressure therein soon falls below that in the rooms. The column of gas again reverses its direction, not so suddenly, since the pressures are less, and moves out of the rooms around to the entry. All three instruments record this reversal. Records of other tests show that some of the gas also

goes from the rooms out the air course, air also traveling in the entry from the outside to help bring back equilibrium. The oscillation may continue for several seconds before equilibrium with the outside air is established.

This test shows the violence that can be manifested by a coal-dust explosion when proper conditions are established. It demonstrates

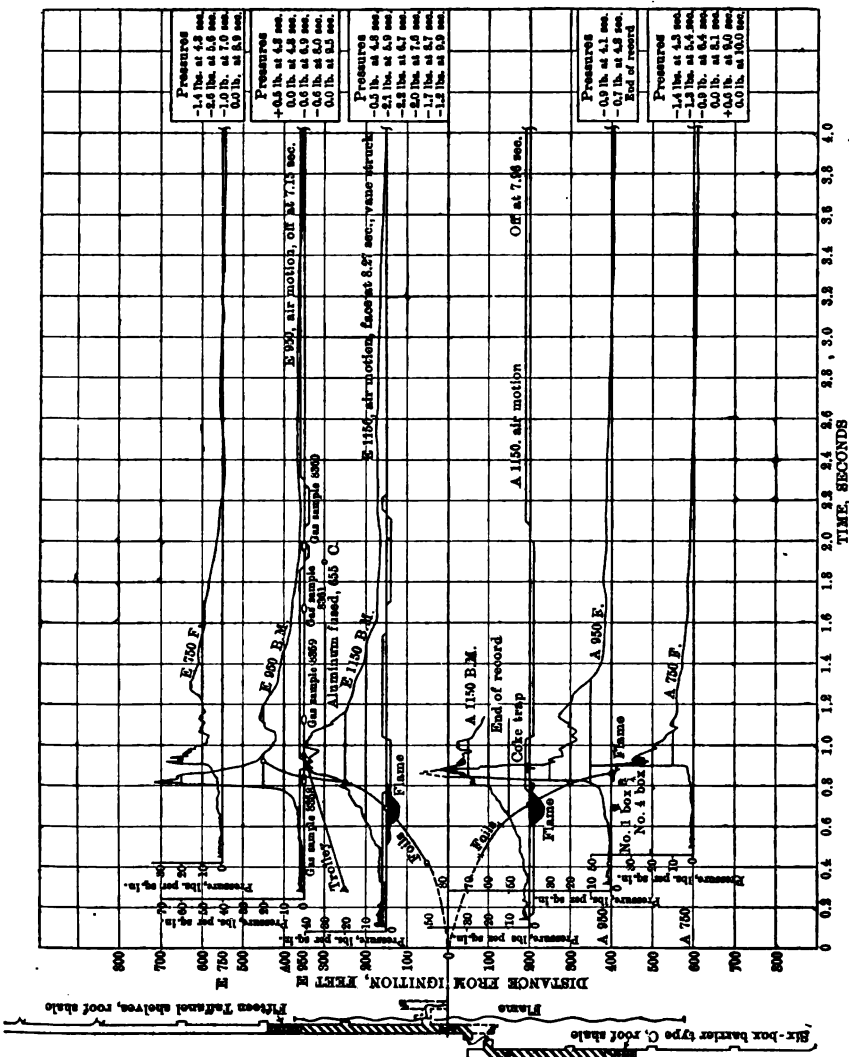


FIGURE 61.—Curve showing results of standard ignition test (No. 388) of 100 per cent 20-mesh Upper Freeport coal dust, of which 10 per cent would pass 200-mesh, loaded at 2 pounds per linear foot, with no gas present.

beyond question the explosibility of this kind of coal dust when dry and pure.

Test 358—Figure 61.—This was a standard ignition test on 20-mesh Upper Freeport seam coal dust, of which 10 per cent would pass 200-mesh. This coal dust is not so explosive as Miller seam

coal dust and the size was coarser. The resulting explosion was violent, but to a less degree than in test 347. The flame curves show a steady increase in velocity to the barriers. As is usual in violent tests, the maximum pressures at E 1150 and A 1150 were due to retonation waves, those at E 950 and A 950 being due to direct pressure from the explosion at that point. The record on the manometer at A 950 was not distinct above 80 pounds, but the pressure was not less than that shown. The flame records show a short and intense flame, this always occurring in a violent explosion. The retonation wave, registered at A 1150 at 0.99 second, can be traced from the maximum pressure at A 950. It will be observed in this test, as in many others, that after the flame is extinguished and the pressures have fallen to atmospheric there follows a series of pressure and rarefaction waves traveling with the velocity of sound. These waves can usually be traced on all the manometers and follow each other for a number of seconds, during which equilibrium with atmospheric pressure outside the mine is established. They can also be traced in the tabulated pressure values.

The air-direction indicators gave the usual records—outward motion until the flame passed at the stations at which the instruments were located, then inward movement until after the flame was extinguished, followed by outward movement, changing to a movement of a long column from the entry to the butts and rooms, the direction of this column reversing after the pressure in the entry has fallen below that in the rooms. This movement frequently continues past equilibrium, and there is a final return of air to the rooms, frequently unrecorded because of low velocities.

This test shows that the coal dust from the Upper Freeport seam is violently explosive when dry and pure.

Test 189—Figure 62.—This test, discussed on page 95, was an ignition test of pulverized Lower Kittanning seam coal dust. This coal dust is much less explosive than any previously discussed in this section; nevertheless a strong explosion developed. The foil curves show increasing velocities throughout the zones. The entry barrier failed and the flame extended 200 feet beyond the barrier. The manometer records show a much greater development of pressure in the air course than in the entry. A retonation wave is evident at A 1150 and was responsible for the maximum pressure. There was a very unusual occurrence in this test. The flame was extinguished at A 900; nevertheless, the maximum pressure at A 750 was as great as at A 950. Careful examination failed to reveal any error in the records or fault in the instruments. The manometers at A 950 and A 750, however, were both of the B. C. D. (British Coal Dust) type, later discarded. These instruments because of the inertia of moving parts, may lag, or in the

event of a hammer-like blow, the marker may shoot too high. The vane of the air direction indicator at E 950 was bent by flying fragments, probably about the time of the arrival of the flame. It should be noted, however, that there was no indication of air moving inward until after the flame reached E 950. The air-direction indicator at E 150 recorded an outward movement for four seconds, then a series of inward movements until equilibrium

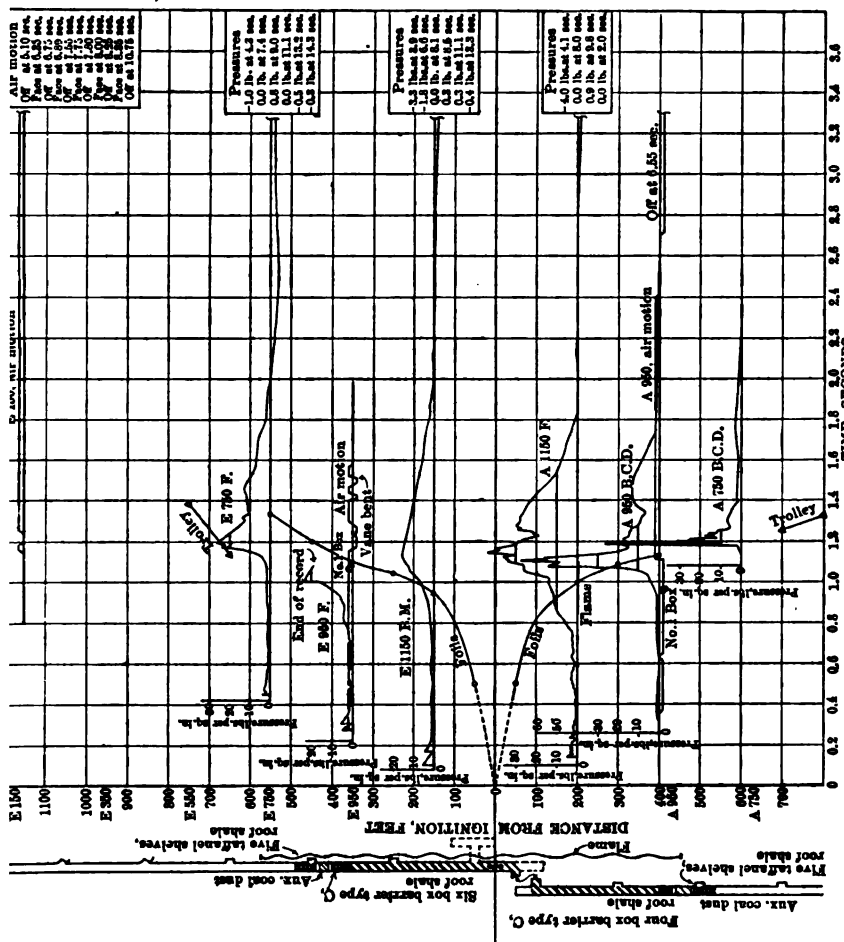


FIGURE 62.—Curve showing results of ignition test (No. 189) of 100 per cent pulverized Lower Kittanning seam coal dust, loaded at 2 pounds per linear foot.

was established. The air-direction indicator at A 950 recorded outward movement until the arrival of the flame; then it reversed very suddenly, the time taken to move from one contact to the other being less than 0.01 second. This was followed by an inward movement of the air, and finally an outward movement to restore equilibrium in the rooms.

It is evident from the test that a violent explosion can be obtained with Lower Kittanning seam coal dust if this dust be dry, fine, and pure.

GROUP 3.—STANDARD IGNITION TESTS ON MIXED DUST.

Five tests are given in this group, showing the gradation of explosibility from a test in which ignition was not obtained to one giving strong ignition. The general information concerning these tests is summarized in the following table:

Summary of standard ignition tests of mixed dust.

Test No.	Figure No.	Coal dust.		Coal dust in mixture.	Gas in air current.	Maximum pressure at E 950.	Time of fall at E 950.
		Kind.	Size.				
455	63	Montana.....	20-mesh.....	<i>Per ct.</i> 60	<i>Per ct.</i> 1.7	<i>Lbs. per sq. in.</i> 2	<i>Seconds.</i>
471	64	Colorado.....	do.....	50	1.7	7	3.05
441	65	Pittsburgh.....	do.....	60	1.9	10	2.45
404	66	Vancouver Island..	Pulverized..	50	.0	19	1.82
292	67	Indiana No. 5.....	do.....	50	.0	31	1.46

These tests are typical of the results obtained with ignition tests on different mixed dusts. The explosibility in this group increases with each succeeding test. This is shown by the increasing pressures and decreasing time taken for the flame to reach E 950. The results of these tests, with the exception of No. 441, have been discussed in Chapter VI. Test 441 has been discussed on page 211.

Test 455—Figure 63.—Ignition was not obtained, the flame extending to E 1150 and A 1150. The tin-foil curves show low flame velocities, decreasing as the explosion progressed. Tests with low flame velocities give longer flame records on the manometers. The flame record on the A 1150 manometer is the longest consecutive record ever obtained, lasting 3.52 seconds. The manometers recorded the shock wave and reflected wave very clearly, these being followed by a series of pressure waves traveling ahead of the flame. About the time the flame was extinguished the pressures fell to and below atmospheric. The air-direction indicators were located at A 950, A 750, and 1B 50 to determine the movement of air in and out of the rooms. The A 950 instrument recorded outward movement from the time of the shock wave until after the flame arrived at A 1150. The velocities during this period were probably not much over that necessary to operate the instrument, since there are three short breaks in the record. The column of moving air divided at the butt entries. The 1B 50 manometer recorded the shock wave, but the velocity of the air moving up the butt subsequently was too low to give a record. The shock wave did not record at A 750, but subsequent outward movement did. At 3.04 seconds the air current had reversed in the butt entries and was moving with sufficient velocity to operate the instrument at 1B 50. The instrument at A 950 recorded this reversed movement

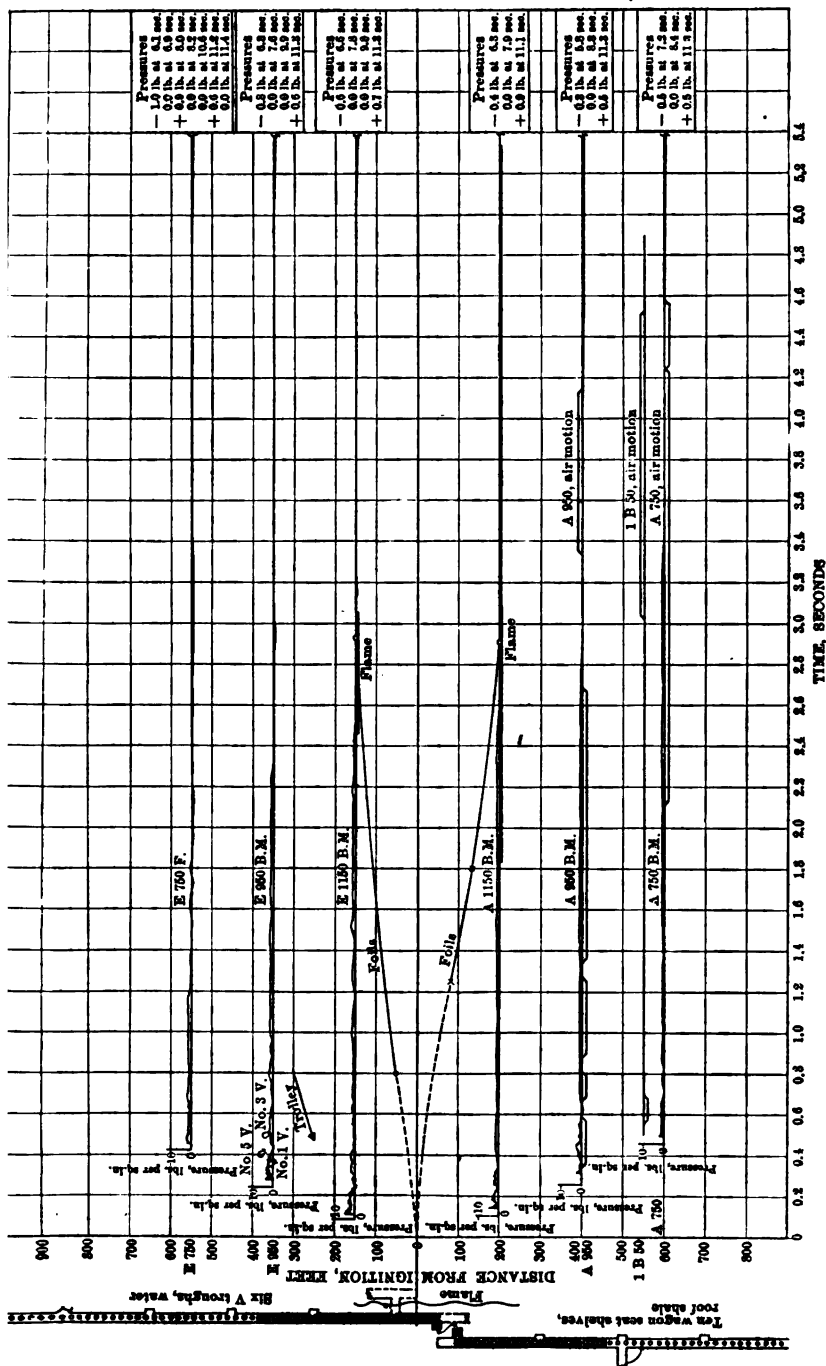


FIGURE 63.—Curve showing results of ignition test of a mixture of 60 per cent 20-mesh Montana coal dust (20 per cent of which was 200-mesh), 30 per cent 20-mesh pit shale, and 1 per cent water, with 1.7 per cent gas.

at 3.35 seconds, but the air still continued to move outby past A 750. The column moving out No. 1 butt must have divided at the air course, some going inby and some outby.

The air movement can be correlated with the flame as photographed on the manometers. It will be observed that the flame record at

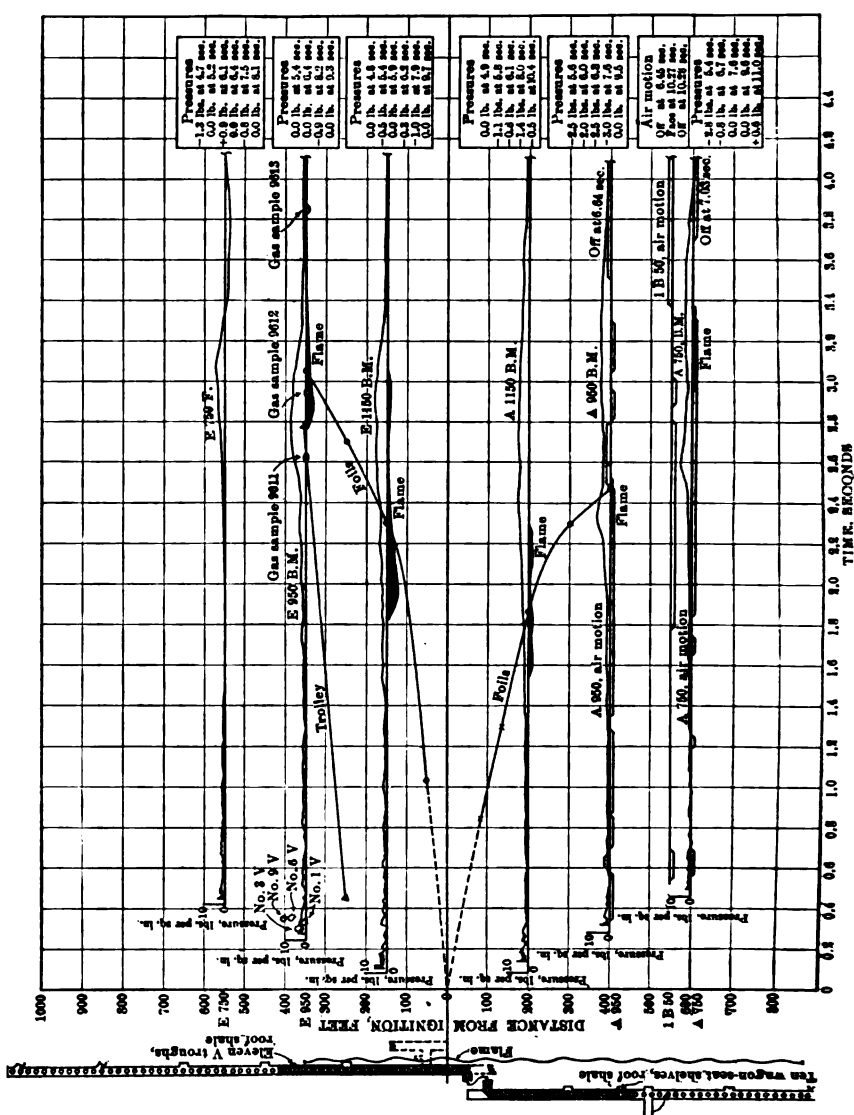


FIGURE 14.—Curve showing results of ignition test of a mixture of 50 per cent 20-month Colorado road dust (20 per cent of which was 200-mesh) and 50 per cent 20-month pit shale, with 1.7 per cent gas (List 471).

E 1150 ceases at about the same time that the air current moving out of No. 1 butt is first recorded. Since the flame did not extend outby E 1150, it is probable that the flame in the entry was entirely extinguished at this time, about 3.05 seconds after ignition. The

gases in the entry then cooled and reduced the pressure below that in the rooms. It would appear that the pressure at A 1150, where the flame was still burning, was intermediate between the pressures in the entry and in the rooms. On this assumption there was a column of gas moving in the air course from No. 1 butt and out the entry.

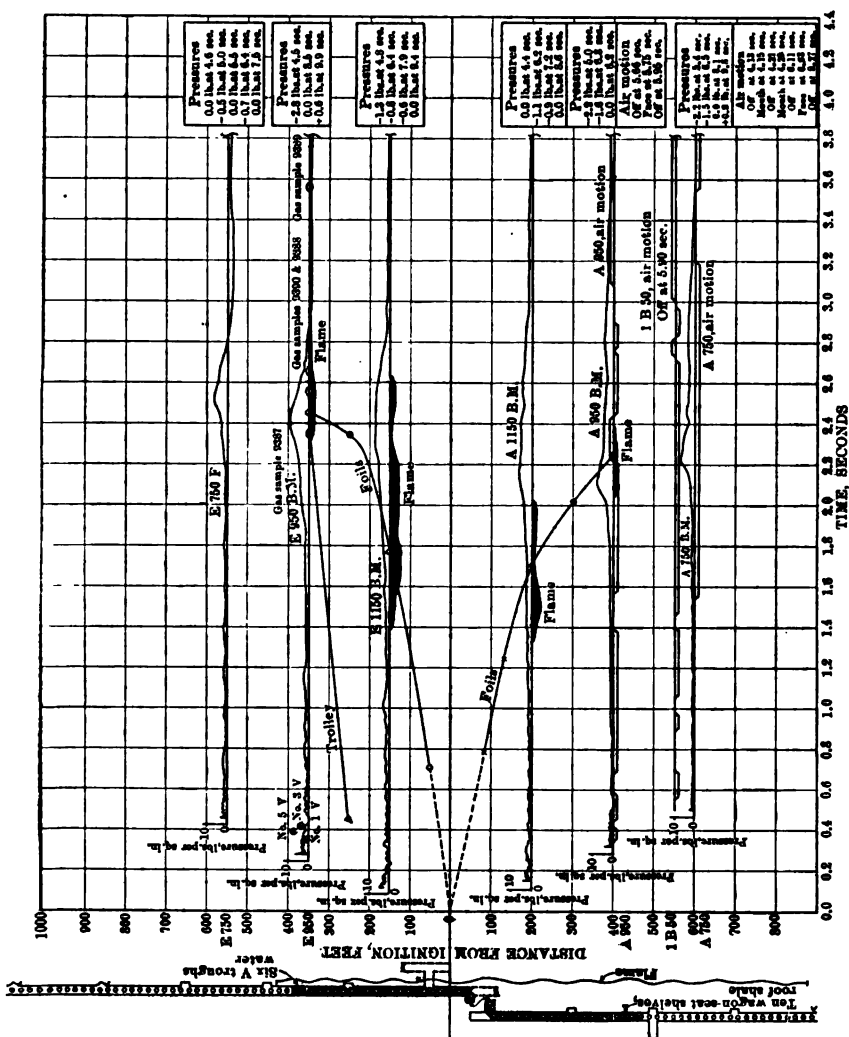


FIGURE 65.—Curve showing results of ignition test (No. 441) of a mixture of 60 per cent 20-mesh Pittsburgh coal dust (10 per cent of which was 200-mesh) and 40 per cent 20-mesh pit shale, with 1.9 per cent gas.

The flame continued to burn in this column of gas, advancing through it with about the same speed that the entire column was moving inward, its position with relation to the walls of the entry remaining practically constant. The result of this was the long-flame record at A 1150.

Test 471—Figure 64.—The explosion developed slowly at first, but the velocity increased steadily as the explosion progressed. This is an example of a dust mixture near the limit of explosibility. A number of pressure waves precede the flame, the rise in pressure being slow. The explosion gave strong and long-continued flame records on the manometers. The barrier in the air course failed and the flame traveled out past A 750, photographing on the A 750 manometer. Because of this continuation of the flame the pressures in the air course did not fall immediately to atmospheric after the

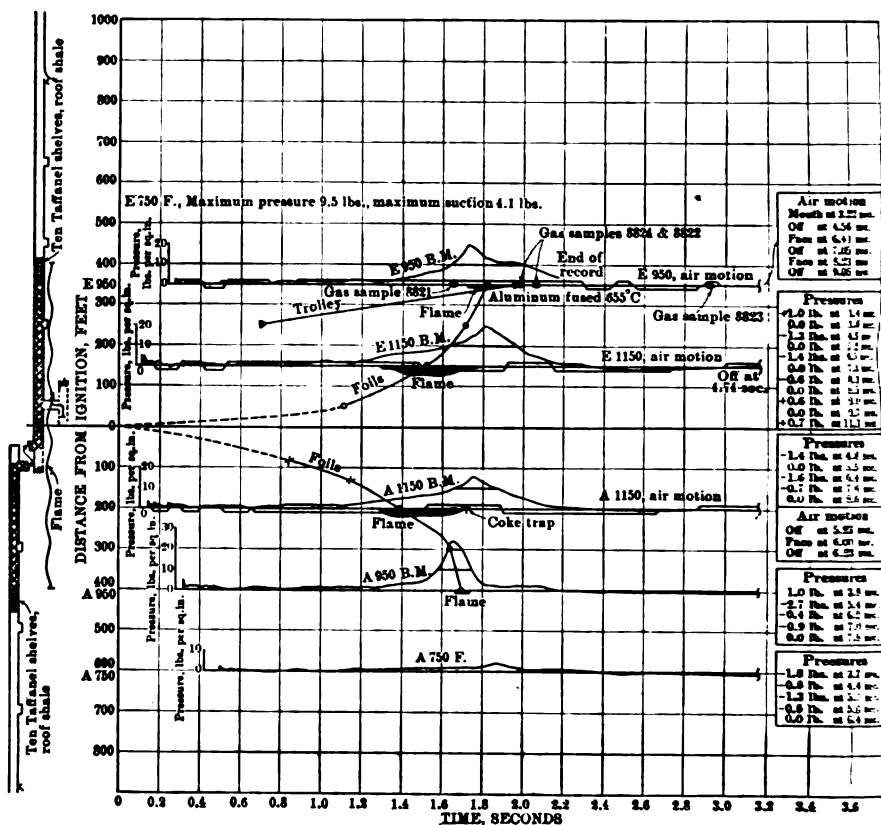


FIGURE 66.—Curve showing results of ignition test (No. 404) of a mixture of 50 per cent pulverized Vancouver Island coal dust (at 1 pound per foot) and 50 per cent pulverized pit shale, with no gas.

flame passed A 950. The air-direction indicators showed gases moving out the air course ahead of the flame, the column dividing at the butt entries. The velocity of the two columns moving out the air course and up the butts was too low to give a continuous record on the instruments at A 750 and 1B 50, respectively. This movement continued until the flame was entirely past No. 1 butt, then the direction of motion reversed, gas coming out of No. 1 butt and moving both in and out the air course. There may have been a short period

from 3.31 seconds to 3.71 seconds when the movement at A 750 was inward, the flame having moved outby the station, but the velocity was too low to give a record if this was the case.

Test 441—Figure 65.—This test is similar in many ways to test 471, the main difference being that the explosion developed somewhat more rapidly with somewhat higher pressures. An explosion of this

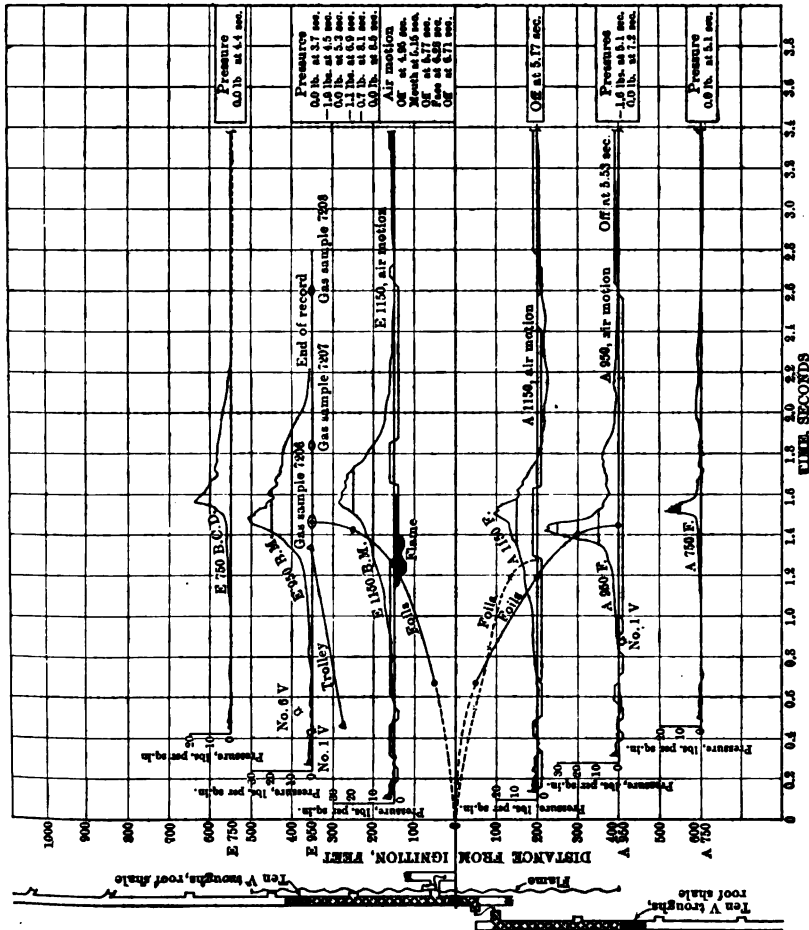


FIGURE 67.—Curve showing results of ignition test (No. 292) of a mixture of 50 per cent pulverized Indiana No. 5 coal (at 2 pounds per linear foot) and 50 per cent pulverized pit shale.

type would probably develop considerable violence in long zones. It will be observed that the air movements have become stronger, the records on the air-direction indicators being more nearly continuous. The tabulated values of the air movement at A 750 show a final movement of air inward. This is more evident in stronger explosions. A point worthy of note is that three gas samples were obtained coincident with the flame photograph at E 950. The analyses of two of these samples are given in Table 8.

Test 404—Figure 66.—This is an example of a test in which strong ignition is obtained. The pressures rise more rapidly, although the curves still have a comparatively smooth appearance. The maximum pressures at E 1150 and A 1150 are probably due to retonation waves assisting the pressure of combustion. The maximum pressures at E 950 and A 950 occur with the arrival of the flame as shown by the flame photograph. The air-direction indicators at E 1150 and E 950 show a vibratory motion in the air column in the early period of this test. This is not always obtained. In this test the waves are traveling approximately with the speed of sound. After the flame passes E 1150 and A 1150 the direction of movement at these points reverses, as is always the case in strong explosions. After the flame is extinguished the movement again reverses, then changes to a movement in the entry and out the air course.

Test 292—Figure 67.—This is an example of an ignition test of mixed dust giving an explosion of some violence. The explosion develops rapidly and the pressures rise in waves of greater magnitude. Strong retonation waves make their appearance and can be traced on the manometers in both entries. The return pressure wave from the butt entries is stronger and affects the manometers considerably. The air-direction indicators show sudden reversals of the gas flow when critical points, such as the passage of the flame, are reached. The general movement of the air, however, remains the same, the difference being in violence and duration.

GROUP 4.—STANDARD PROPAGATION TESTS OF MIXED DUST.

Five tests are given in this group, showing gradation of explosibility from a test in which propagation was not obtained to one giving strong propagation. The general information concerning these tests is summarized in the following table:

Summary of standard propagation tests of mixed dust.

Test No.	Figure No.	Coal dust.		Coal dust in mixture.	Gas in air current.	Maximum pressure at E 950.	Time of fall at E 950.
		Kind.	Size.				
435	68	Pittsburgh.....	20-mesh.....	Per cent. 40	Per cent. 1.1	Lbs. per sq. ft. 1	Seconds. —
414	69	Kentucky.....	do.....	30	.8	2	3.32
439	70	Pittsburgh.....	do.....	40	.9	3	1.86
383	71	British Columbia.....	do.....	40	1.8	19	1.08
333	72	Pittsburgh.....	Pulverized..	75	.0	35	1.07

Tests 435 and 439 have been discussed in Chapter V, tests 414 and 383 in Chapter VI, and test 333 in Chapter VIII. These are typical of the results obtained from this standard method of testing.

there being a steady gradation of properties with change in the composition of the dust tested. There are, however, certain properties common to all which can be noted in the examples given. The shock wave and the reflected wave are, as always, the first things recorded by the manometers. Following this is a pressure wave from the burning Pittsburgh coal dust in the ignition zone. If the mixed dust outby is slow in igniting, the pressure may fall again after this wave passes before strong waves from the burning mixed dust are recorded. If the mixed dust burns rapidly, there will be a steady rise in pressure, the first waves from the burning mixed dust arriving before the pressure from the burning Pittsburgh coal dust in the ignition zone has fallen. The pressure wave from the burning dust in the ignition zone arrives at E 1150 and A 1150 at about 0.33 and 0.37 second after ignition, respectively, traveling with the velocity of sound under the conditions then obtaining. This wave can be traced on all the manometers. As a rule the record of this wave shows 5 or 6 pounds pressure. This pressure and the pressure given by the shock wave are not considered in stating the maximum pressure. Thus in test 414 (see fig. 69), the shock wave pressure at E 1150 was 5 pounds, the ignition zone pressure was 6 pounds, while the pressure from the burning mixed dust was only 2 pounds. The maximum pressure in this test was 2 pounds, given by the burning mixed dust. The preceding higher pressures are not considered, since they do not come from the mixed dust under test.

The tin-foil at E 1250 is usually fused from 0.25 to 0.4 second after ignition. Variation in the pointed shape of the flame is probably responsible for this variation in the time of this rupture. The time is, however, as might be expected, independent of the dust loading outby the ignition zone.

The air-direction indicators, irrespective of their location, show outward movement of the air from the time of the arrival of the shock wave until after the flame has passed the station in question or is extinguished. Occasionally a wave traveling inby with the velocity of sound is recorded shortly after the shock wave, but these are of short duration, usually not over 0.05 second, and are vibrations traveling through the air column rather than any actual displacement of the entire column inward. The truth of this will be evident when it is considered that the force required to change the velocity of a long air column from 50 or more feet per second in one direction to an equal velocity in the opposite direction in 0.02 to 0.05 second is of an order much higher than the pressures obtaining at the time these waves occur.

Test 435—Figure 68.—Propagation was not obtained. The flame velocities decreased after leaving the ignition zone, showing that the mixed dust was quenching the flame. It should be noted that the

tin-foil rupture at A 1150 does not coincide with the flame photograph. It is probable that the foil was only partly fused and was finally torn out by air movement. The pressure at any one station also decreases as the flame dies out. Pressure peaks can be traced

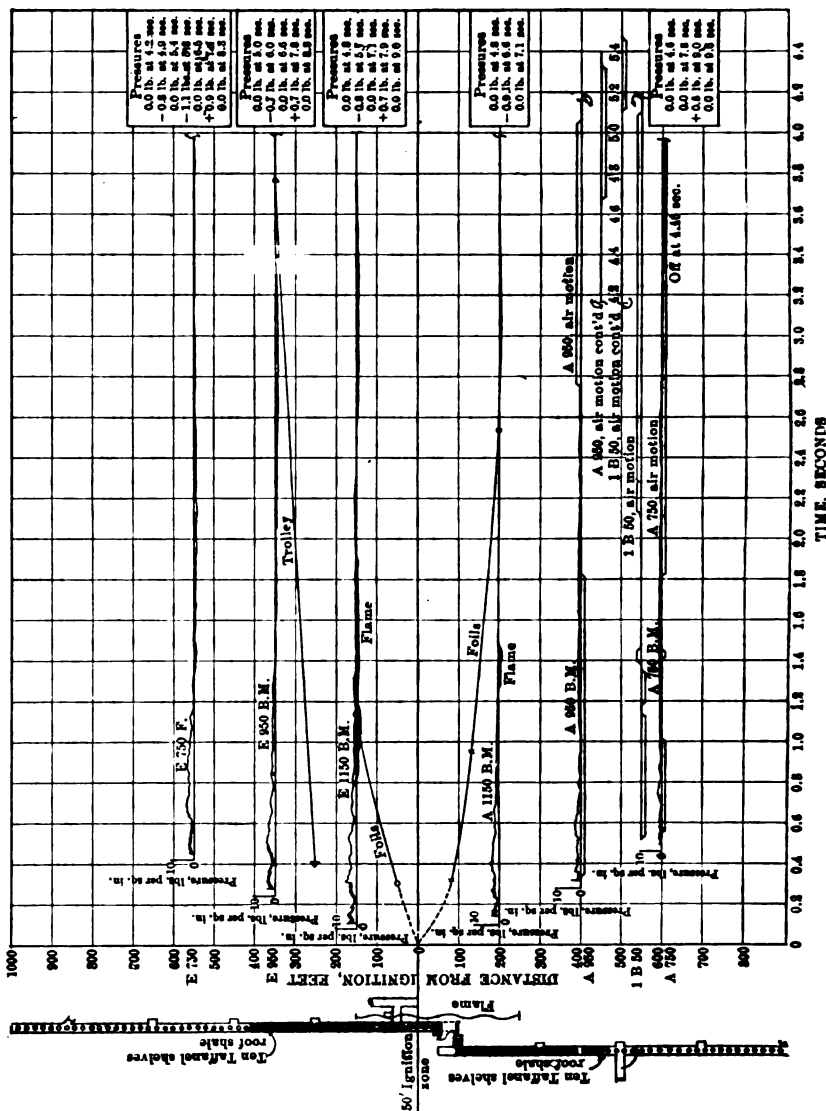


FIGURE 68.—Curve showing results of standard propagation test (No. 435) on mixture of 40 per cent 20-mesh Pittsburgh coal dust (10 per cent of which was 200-mesh) and 60 per cent 20-mesh pit shale, with 1.1 per cent gas.

across from curve to curve. The air-direction indicators show a strong outward movement in the air course, the current dividing at the butts. After the flame is extinguished the air moves out of the rooms and goes both in and out the air course. There is a final movement out No. 1 butt to restore equilibrium.

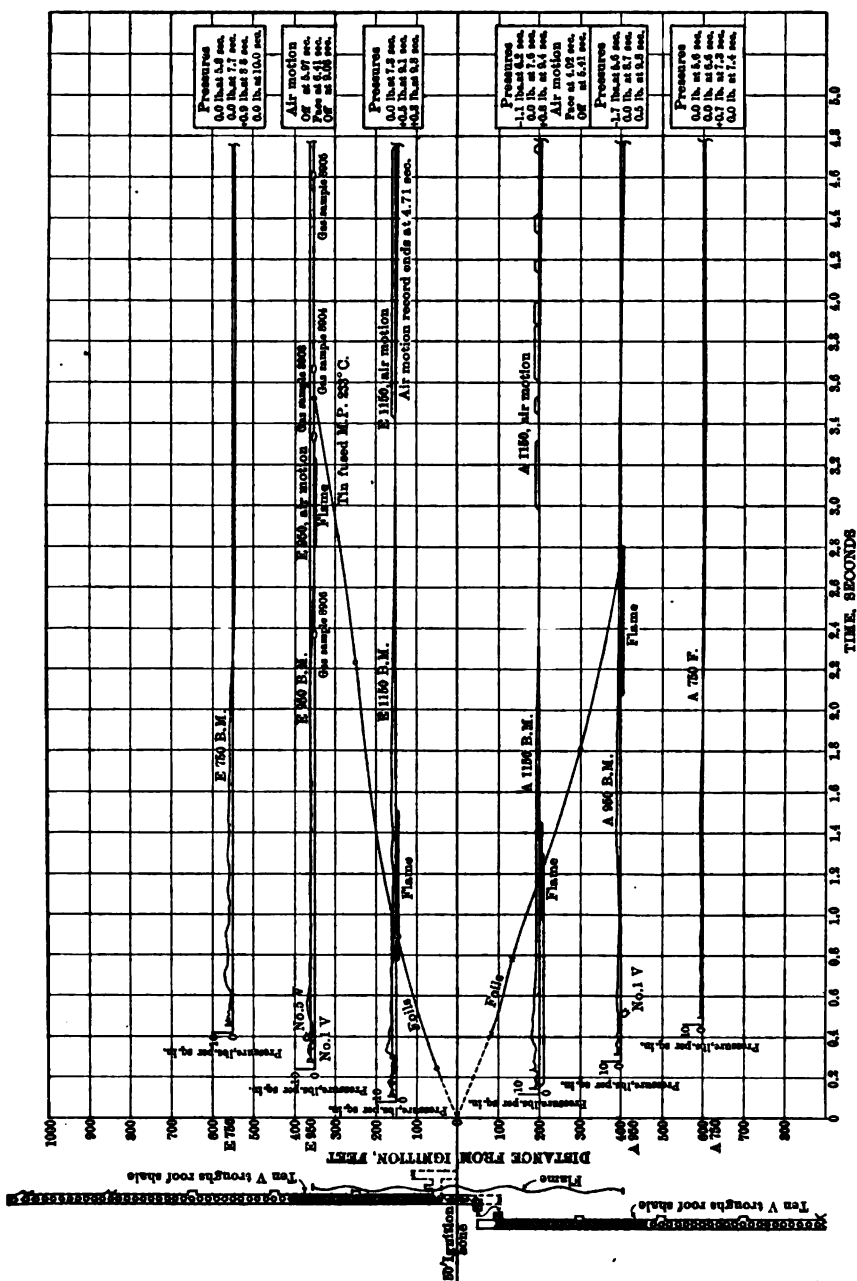


FIGURE 69.—Curve showing results of standard propagation test (No. 414) on a mixture of 80 per cent 20-mesh (40 per cent 200-mesh) Kentucky coal (at 1 pound per linear foot) and 70 per cent 20-mesh pit shale, with 0.8 per cent gas.

Test 414—Figure 69.—Very weak propagation was obtained. The flame velocity decreases steadily throughout the zones. At E 950 rupture of the foil again occurs after the flame photograph. It is very probable that complete propagation would not have been obtained through a long zone of dust of this composition.

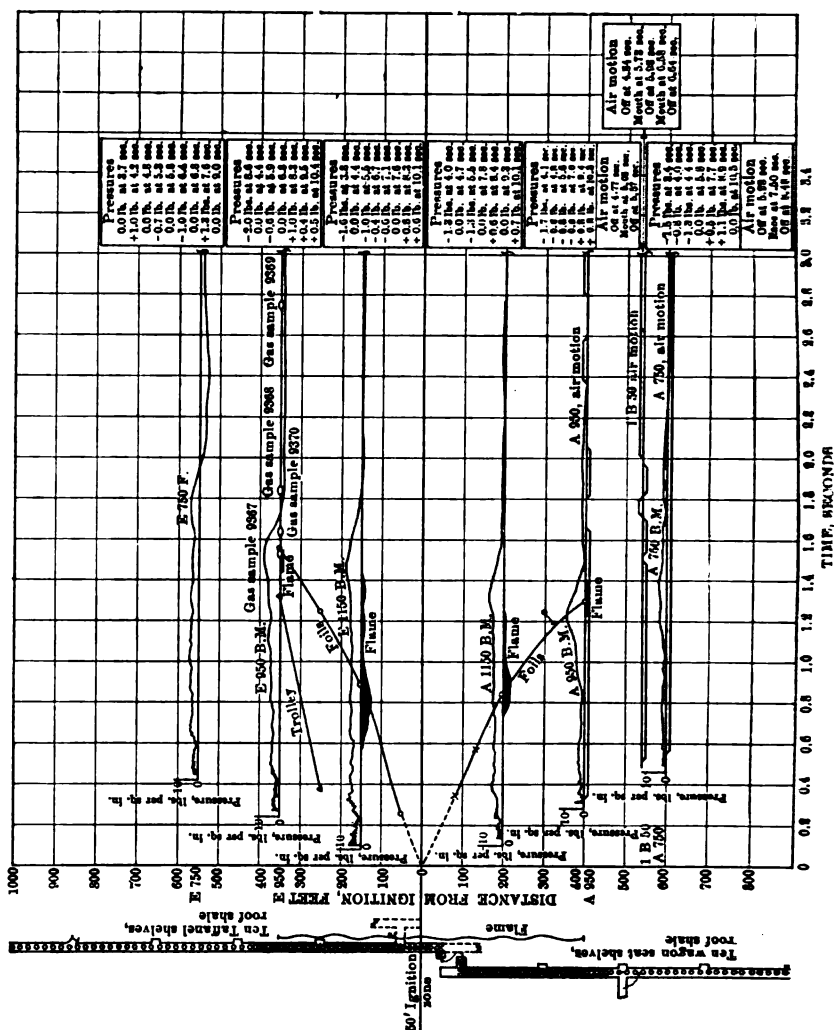


FIGURE 70. Curve showing results of standard propagation test (No. 439) of a mixture of 40 per cent 20-mesh and 60 per cent 40-mesh Pittsburgh coal dust (at 1 pound per linear foot) and 60 per cent 20-mesh pit. sh., with 0.6 per cent gas.

Test 439—Figure 70.—The flame increased steadily in velocity while traveling through the dust zone. The flame photograph shows a greater intensity than in the weak tests just given. The pressure waves recorded by the manometers are of greater amplitude and retonation waves begin to appear. As the explosions increase in violence the pressures fall further below atmospheric after the flame is extinguished, nearly 5 pounds suction being recorded at E 750 in

this test. The violence of the explosion is, however, not the only factor in the case. The air movement differs mainly in intensity and duration, the order of movement being practically the same.

Test 383—Figure 71.—This test gave strong propagation. Pressures in the test zone increase steadily from the ignition zone pressure wave to the maximum. The various waves are more pronounced, and a retonation wave starting from A 950 at the time of maximum

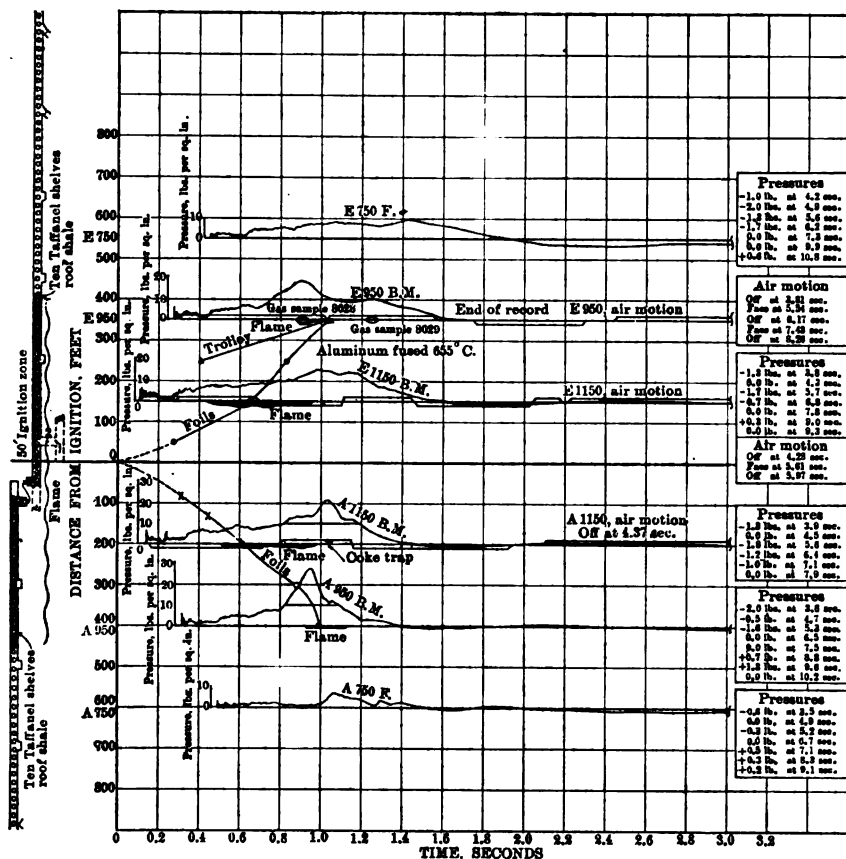


FIGURE 71.—Curve showing results of standard propagation test (No. 383) of a mixture of 40 per cent 20-mesh (40 per cent 200-mesh) British Columbia coal (at 1 pound per linear foot) and 60 per cent 20-mesh pit shale, with 1.8 per cent gas.

pressure can be traced. This starts from A 950 at 0.95 second, reaches A 1150 at 1.03 seconds, E 1150 at 1.13 seconds, E 950 at 1.22 seconds, and E 750 at either 1.33 or 1.41 seconds. This wave decreases in velocity as it progresses.

Test 333—Figure 72.—This test gave a violent explosion, the results of which have been discussed in Chapter VIII (see p. 395). The load-

ing in this test was a mixture of 75 per cent pulverized Pittsburgh coal dust and 25 per cent water. The flame velocity increased rapidly through the zone. No barriers were used, there being 100-foot rock dust zones 50 feet outby the end of the coal dust zone. These were

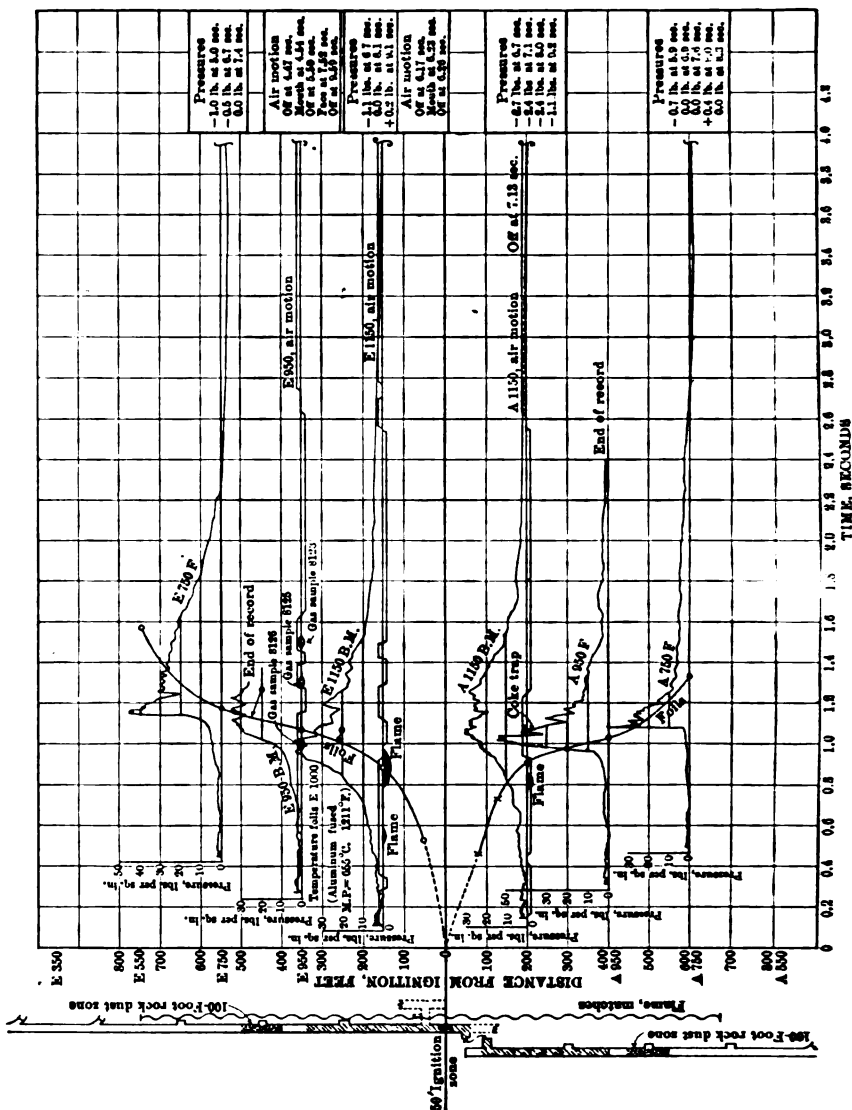


FIGURE 72.—Curve showing results of standard propagation test (No. 383) of a mixture of 75 per cent pulverized Pittsburgh coal dust and 25 per cent water, loaded at 2 pounds per linear foot, with no gas.

too short to quench the flame entirely, although they reduced the velocity. The pressure records show rapid rise and strong retonation waves. At E 1150 the maximum pressure occurred during the passage of the main body of flame, which is unusual, retonation waves generally causing the maximum. The passage of the flame beyond the

ends of the dust zones complicates the pressure records considerably. The air movement follows the usual course, previously described, there being some additional waves recorded by the instruments at E 1150 and A 1150.

GROUP 5.—VARIOUS SPECIAL TESTS.

Six tests are given in this group. These include tests with origin at different parts of the mine. The tests given in figures 73 to 78 are:

Test 391, special test with origin at E 1300.

Test 417, test with origin near mouth of mine.

Test 418, test with origin near mouth of mine.

Test 466, test with origin at face of No. 1 butt.

Test 148, test with origin at face of No. 2 butt.

Test 330, test with origin at face of No. 3 room.

Test 391—Figure 73.—This test was made to determine whether or not a standard blown-out shot from the cannon at the face of the entry would ignite pure pulverized Pittsburgh coal dust 25 feet away. A previous test has shown that dust 50 feet away would not be ignited. The dust in test 391 was distributed from E 1275 to E 1150 and A 1150. The dust was ignited by the shot, but it is evident from the curve that it would not be possible to obtain ignition at a much greater distance. In this case it required over a second for the burning dust to develop sufficient pressure to drive the flame outby the 1250 cut-through. Once started, however, the explosion velocity increased rapidly through the zone, the explosion extending 200 feet beyond the zone through the dustless entry to the barriers, which extinguished the flame. The flame velocities fell after the dust zone was passed, but the pressures increased. In this case the maximum pressures at E 1150 and A 1150 were coincident with the passage of the flame. The maximum pressures at E 950, E 750, and A 950 were caused by waves preceding the flame. The air-direction indicators show that during the first second of the explosion a series of waves were traveling both in and out. The first waves traveled with the velocity of sound, but the velocity decreased with each succeeding wave. After the explosion was well started the movement did not differ from the ordinary.

Test 417—Figure 74.—This was one of the series to determine how near the pit mouth an explosion to travel into the mine could be originated. This series has been discussed at the beginning of Chapter VII. In test 417 the cannon was at E 280, pointing outby. The flame was somewhat slow in starting, but once started it attained high velocities. It extended 50 feet outside the pit mouth, a distance of 330 feet beyond the outer end of the dust zone and inby to E 1050, a distance of 470 feet beyond the inner end of the dust zone. The velocities increased to the inner end of the zone, then decreased.

The manometers recorded high pressures in by the cannon. Up to 0.6 second the manometers show only a succession of small waves. At this time the flame started in by with high velocity and pressures rose rapidly. The air movement is interesting and simple. At

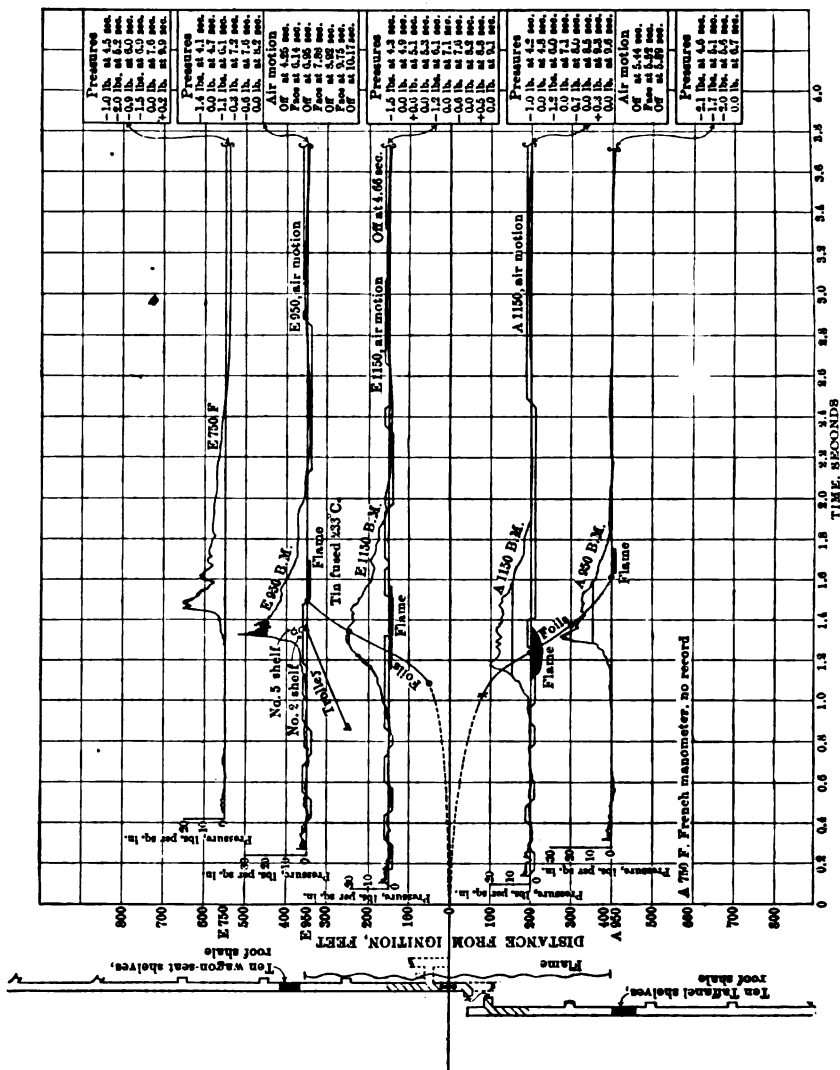


FIGURE 72.—Curves showing results of special test (No. 201) to determine whether or not a standard blown-out shot from the cannon at the face of the test with light-pure pulverized Pittsburgh coal dust (loaded at 2 pounds per linear foot) 25 feet away, i. e., dust/less from cannon for 25 feet.

E 150 the movement, with two exceptions, was outward until the pressures had fallen below atmospheric. The exceptions are a wave traveling inward after the shock wave and a short break just after the flame passed. The movement at E 350 was inward until the flame passed, then outward until the pressures had fallen below

atmospheric. After this both instruments recorded air moving inward to fill the vacuum.

Test 418—Figure 75.—This test also had its origin near the pit mouth. The cannon was at E 180 pointing outby. The explosion was very slow in developing, but once started its velocity increased steadily. Large volumes of flame were projected from the pit

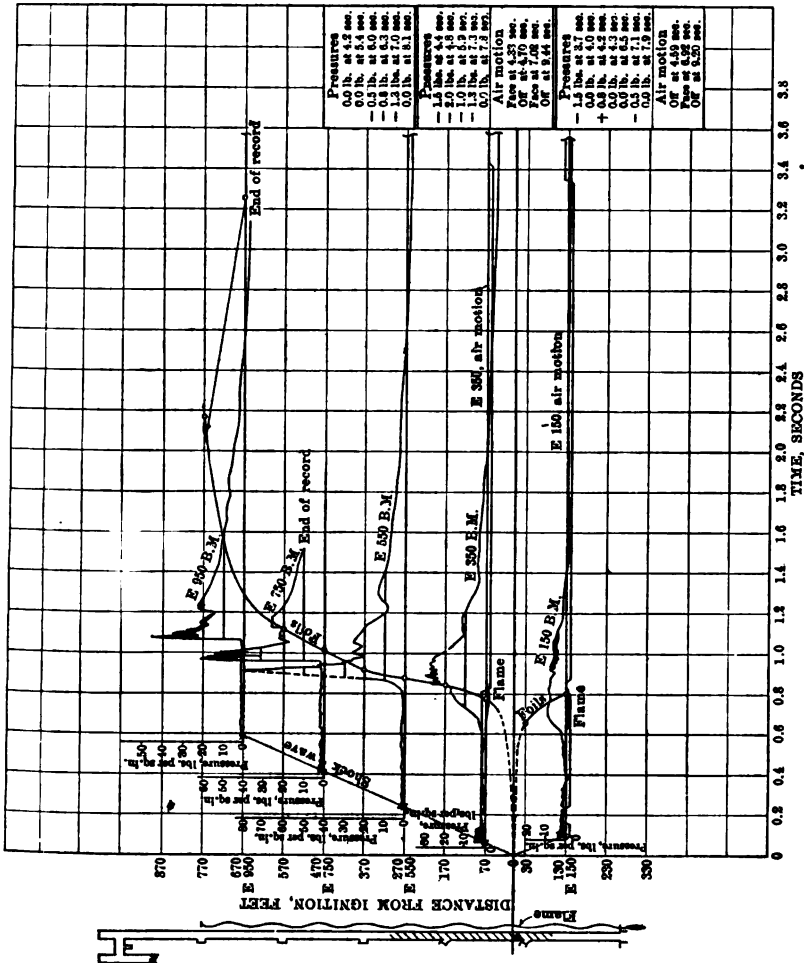


FIGURE 74.—Curve showing results of special test (No. 417) to determine how near the pit mouth an explosion traveling into the mine could be originated. Pulverized Pittsburgh coal dust was used, loaded at 2 pounds per linear foot, with no gas present.

mouth for several seconds. The indicated flame velocity from E 250 to E 350 was 36 feet per second, a very low figure.

Three distinct flame photographs were obtained on the E 550 manometer. Two are plotted; the third was beyond the range chosen for plotting for this test and is listed. To produce this record, the flame must have passed the station three times. A

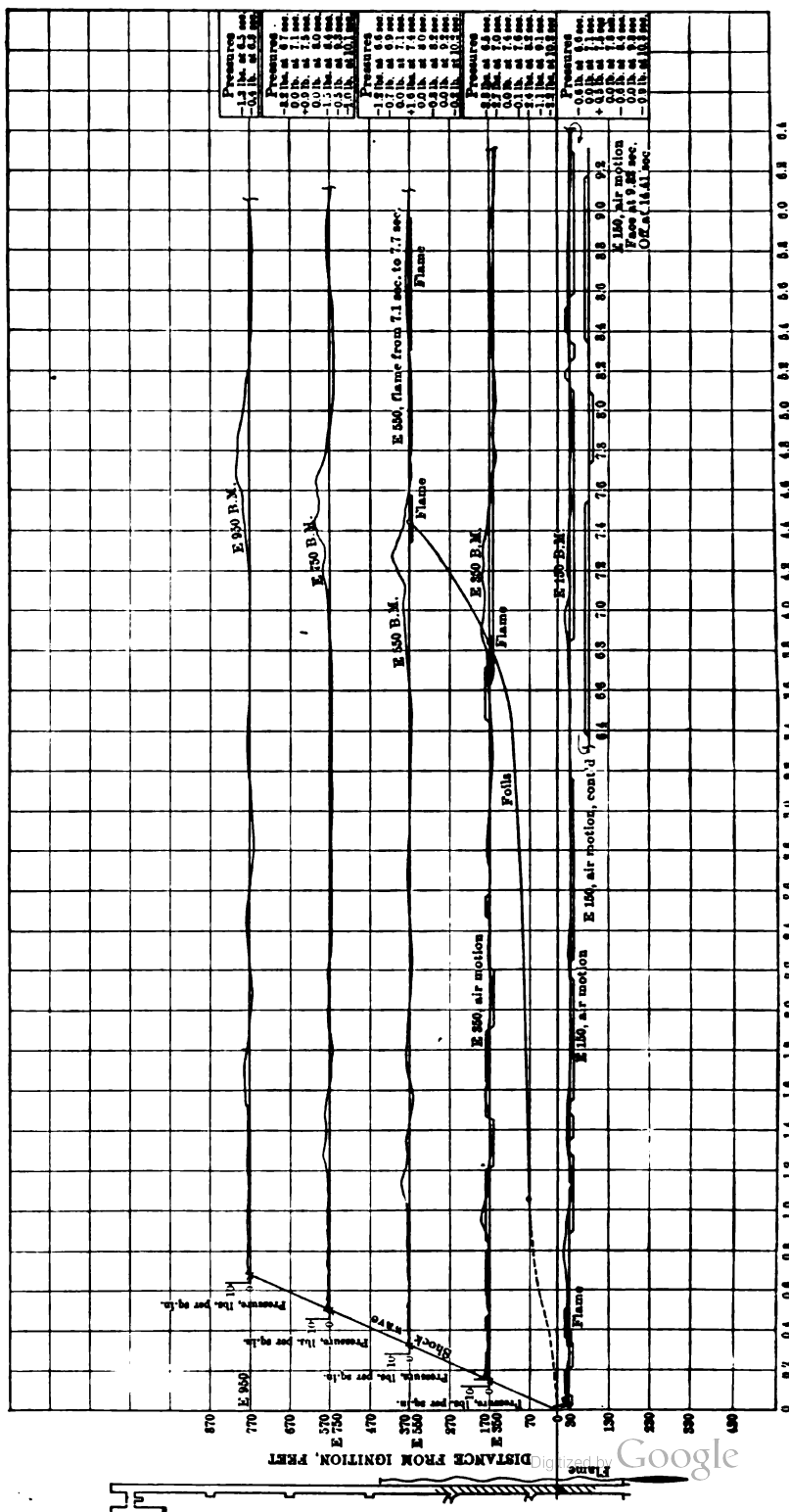


FIGURE 75. Curve showing results of special ignition test (No. 418), originating near the pit mouth with cannon at E 150 pointing outby. Pulverized Pittsburgh coal dust (loaded at 2 pounds per linear foot) was used with no gas present.

large number of waves traveling in the entry are shown by all the manometers. One of these, recorded at E 150 at 0.8 second, came from the flame which had passed outby this station. It is interesting to note that this wave, moving inward, passed directly through the zone of combustion that was also moving inward and is recorded with increased force on the inby side of this combustion zone. Later on the combination of waves passing inward with waves reflected from the entry faces makes tracing more difficult. The series of very strong waves sent out by the flame beginning at about 3.8 seconds is, however, easily traced. These waves traveled in both directions from the flame. Waves occurring after the flame was extinguished can be traced in the tabulated pressure values. The air movement at E 150 showed outward movement with one inward wave before the flame passed the station; then there was a short inward movement, after which the movement became steadily outward for 5.1 seconds. There were, then, a number of reversals in the next three seconds, the final movement, after all flame was extinguished, being inward. The air-direction indicator at E 350 showed inward movement when pressure waves were recorded on the manometer, and outward movement when suction waves were recorded, until the flame approached the point; then the movement was probably steadily inward. After the flame passed the movement reversed and remained outward during a period in which there were four reversals at E 150. The final inward movement was too weak to record at this station.

Test 466—Figure 76.—This was one of the tests to determine the relative effect of weak and strong stoppings. This series is discussed in Chapter VII. In test 466 dust was loaded in both butt entries, the cut-throughs were open, and the ignition was at the face of No. 1 butt. The resulting explosion was weak. The explosion traveled out No. 1 butt, and down the air course with low velocities and pressures, but did not travel completely through the dust zone in No. 2 butt. This condition was found to obtain in all tests. The flame never traveled to the end of both butt entries, irrespective of the butt in which the explosion was originated.

The length of the flame photographs in this test is worthy of note. The pressures were not high, this being the limiting mixture. The air moved out of No. 1 butt ahead of the flame and divided at the air course, moving both in and out. It is probable that after the flame was extinguished the reverse action occurred, but the movement was too weak to affect all the instruments.

Test 148—Figure 77.—This test, discussed in Chapter VII, was one of the early tests with the origin in No. 2 butt. It is important to note that although No. 2 butt was loaded throughout its entire length with pulverized coal dust the maximum pressure at any

station was 13 pounds and the flame velocities were not high. A similar test in the main entry would have given much higher pres-

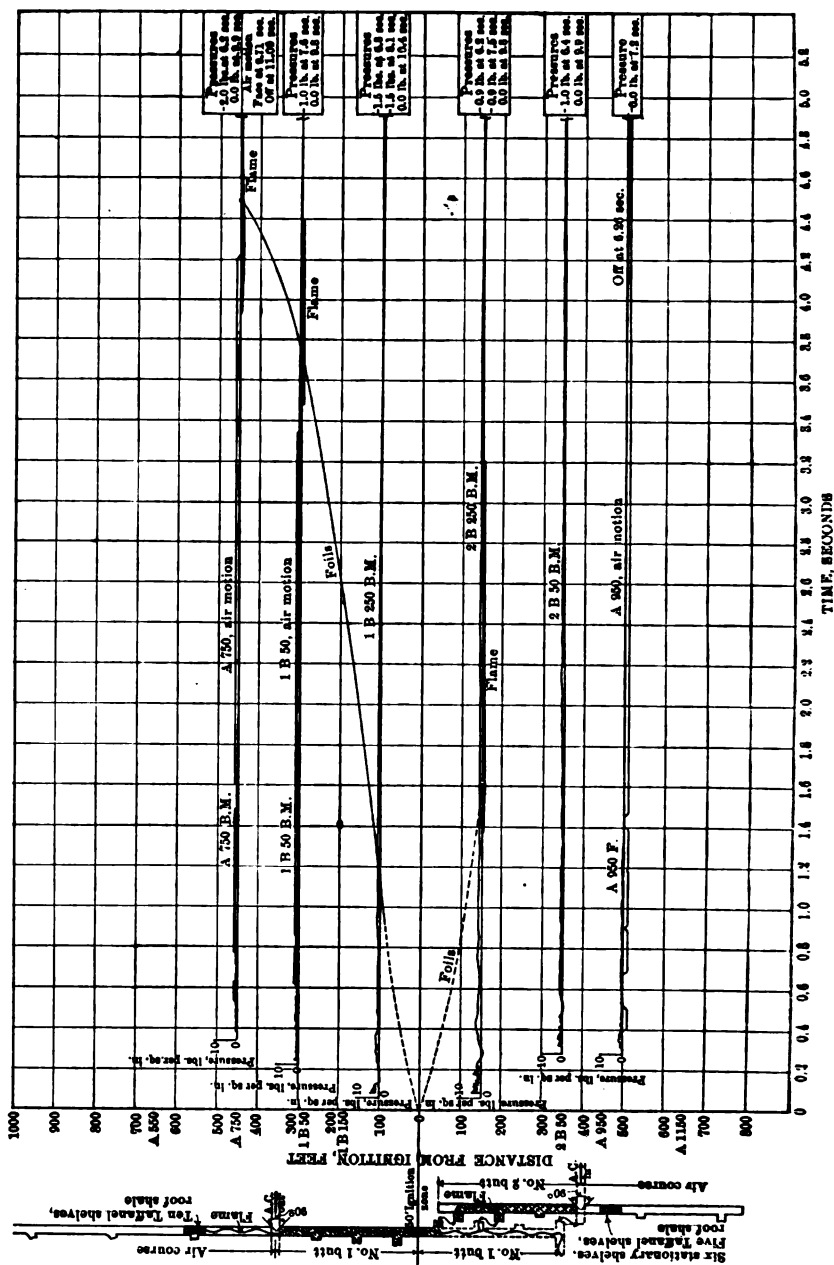


FIGURE 76.—Special propagation lost (No. 405) in No. 1 butt to determine the relative effect of weak and strong stopplings. A mixture of 80 per cent pulverized Pittsburgh coal dust and 20 per cent pulverized pit-shale dust was used, with no gas present.

tures and velocities. The cause of this has been variously conjectured. The explanation of the effect of side openings to the butts and

rooms was considerably discounted by the results of the tests on the effect of weak and strong stoppings. The fact that pressure waves from No. 2 butt hit squarely against the wall of the air course is one suggested explanation. Violent waves, such as are obtained in the main entries, have been noticeably absent in the butt entries. This can be observed in the present case. The air-direction indicator at

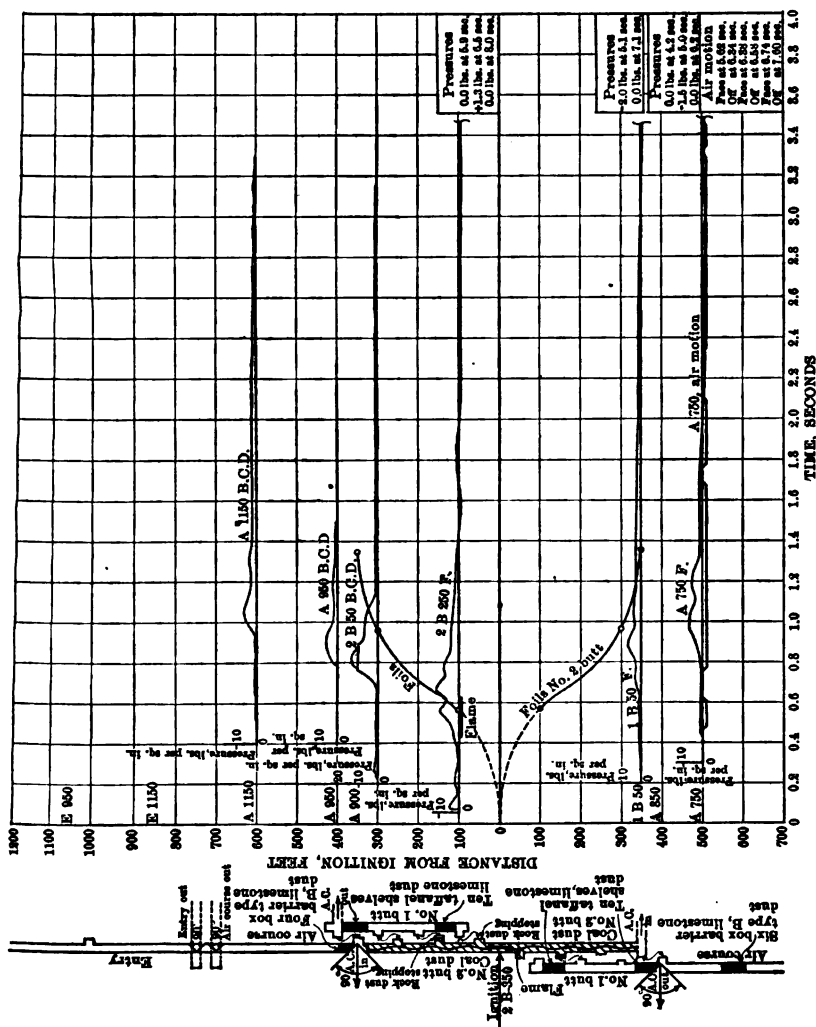


FIGURE 77.—Special test made in No. 2 butt to try out proposed device for stopping explosions. Pure pulverized Pittsburgh coal dust was loaded in No. 2 butt and the two open cut-throughs to No. 1 butt.

A 750 showed outward movement for a considerable period after the flame was extinguished, after which the air moved inward.

Test 330—Figure 78.—This is an example of an explosion affecting several rooms at once. Four rooms off No. 1 butt (all that were driven at that time) were loaded with pulverized Pittsburgh coal dust. This test has been discussed in considerable detail on page 360,

FIGURE 7b. —Curve showing results of special test (No. 330) in which four rooms were loaded with pulverized Pittsburgh coal dust at 4 pounds per linear foot, and both butt entries and the air course were rock damped at 6 pounds per linear foot.

amount of dust used. This pressure was long continued, due to the large volume of the rooms as compared with the butt entries through which this pressure had to escape and also probably because the explosion took a considerable time to travel through all the rooms. A

considerable number of waves were sent out No. 1 butt and down the air course ahead of the explosion. Waves are, however, more evident in No. 2 butt and at 1B 250, where the absolute air movement was probably much smaller. It will be observed that after the flame passed A 750 the pressures at A 750 and 1B 50 began to fall in long sweeping curves much different from those ordinarily recorded in the main entries. There was during this period a steady rush of gas out of the rooms and out of the air course. This continued movement drove the flame ahead of it, possibly as far as A 550. There was also a steady movement of air in the air course and out the entry. The pressures in No. 2 butt and at 1B 250 fell less evenly, probably because the stations are not on the direct line of gas movement, 1B 250 and 2B 250 being toward dead ends. It took considerable time for the large volume of heated gases in the rooms to become cooled and reduced below atmospheric pressure, the flow outward continuing for this period. As soon as the pressure fell below atmospheric, the gas column reversed its movement and traveled back into the rooms to fill the vacuum.

This test shows that the type of explosion developed in a number of rooms differs from that developed in long parallel entries. Pressures and probably temperatures will not be as high, but the volume of gases heated is much greater, which results in long continued gas movements. The slower travel of the flame in the large areas and the long time taken to cool the gases is much more favorable to the starting of fires in timbers or gobs. The effect of long continued heating is shown by the fact that the gold foil melting at $1,967^{\circ}\text{F}$. ($1,064^{\circ}\text{C}$.) was fused in this test whereas the most violent test in the entry, in which the temperatures were probably much higher, fused only the silver foil, melting at $1,760^{\circ}\text{F}$. (960°C .). Moreover, in the room tests it was necessary after every test to extinguish fires smoldering in some of the posts, whereas the ignition of wood fragments in the main entries is a very rare occurrence. This was, moreover, an intensive test on the rock-dust zones under unfavorable conditions, but as stated in the discussion in Chapter VII, the different results given by the different forms of flame indicators rendered it hard to say whether or not the rock-dust zones were successful. Further testing on this line is proposed.

APPENDIX.

PART 1.—GLOSSARY OF TERMS DEVELOPED TO DESCRIBE CONDITIONS IN THE EXPERIMENTAL MINE.

As work at the experimental mine progressed, it became necessary to invent or adapt phrases which would designate in two or three words recurring conditions, the full description of which would require a paragraph. These terms have been used in this bulletin, as they were used in the tests, and are accompanied in various places by descriptions which clarify their meaning. After such a description has been once given the term is used without further explanation. In order to facilitate the reading of the bulletin, however, a glossary of the more important recurring terms is given herewith.

Advance wave or waves.—The air pressure wave or waves preceding the flame in a coal-dust explosion. The bringing of the dust into suspension is accomplished by such waves and the violent eddies resulting therefrom.

Air course.—The name given to the left-hand or east passage of the pair of main passageways in the experimental mine, regardless of the direction of air travel.

Automatic sampler.—An instrument designed to take samples of gases at a predetermined point during an explosion or preceding or following it, as desired. It is described in detail on page 52.

Barrier.—See rock-dust barrier.

Blast.—Synonymous with "shot."

Cannon.—The cannon used to start explosions in the experimental mine is of steel about 24 inches in diameter and 36 inches long, with a 2-inch hole, 21½ inches long, drilled in the center.

Chronograph.—An apparatus for electrically recording explosion phenomena simultaneously with a continuous time record. The instrument is in the observatory. It is described in detail on page 39.

Coal distribution per linear foot of mine entry.—The unit generally used for convenience in figuring the distribution of the dust loading for an explosion in the experimental mine. The real basis of the distribution is the weight of dust per cubic foot of air space in the specified section of the passageway.

Coal distribution per unit of space in mine entry or room.—The total weight of coal dust present divided by the volume of air in the same area of the mine. The dust placed in the mine may be reported on this basis, but it can not be known whether or not all this dust is actually in suspension at the time of the explosion.

Coal dust.—The general name for coal particles of small size. In experimental-mine testing, particles which will not pass through a 20-mesh screen (openings one-thirty-second inch square) are not considered as coal dust. Unless otherwise stated or indicated in the text, the term "coal dust" as applied to particular tests refers to dust prepared from Pittsburgh seam coal.

Coal dust, density of loading.—The quantity of coal dust per cubic foot of space in an average section of a specified entry.

Coke or coked dust.—Coal dust which has been coked by the heat of an explosion and has assumed different forms under different conditions usually found near the origin of the explosion and also where the velocity of the explosion is low, as in a room or wide place, always provided there is at that point an excess of coal dust over that needed for combination with oxygen. The volatile matter of coal dust seems to burn first and, if the coal is a coking coal, coke is formed of one kind or another, depending on the position, temperature, size of dust, and velocity of explosion.

Coke bubbles or globules.—Isolated particles of coke, more or less spherical and usually hollow, cooled while still in suspension, retaining their own shape without aggregation. They are usually found on the floor after explosions.

Coke crust.—A thin layer of coke of considerable area compared with its thickness, deposited, while plastic, on some surface to which it sticks.

Cross shelves.—Shelves consisting of 3 by 12 inch planks placed across the entry about 1 foot below the roof, spaced 10 feet between centers. The ends are recessed into the ribs. Part of the dust is placed on these shelves in explosion tests. These shelves provide for the most effective distribution of the dust by the advance waves and they simulate cross timbers covered with float dust.

Cut-through, crosscut, or break-through (in rooms).—A passage cut through the coal, connecting two parallel entries. In the experimental mine these have been made at regular intervals between the entry and air course, between the two butts driven off the air course, and between rooms.

Density of dust cloud.—The number of ounces of coal dust per cubic foot (or grams per cubic meter) of space, suspended in the air or gases in a specified zone.

Detonation.—A violent chemical reaction resulting in flame and pressure, such as an explosion of mercury fulminate. As used in connection with a coal-dust explosion, it refers to an extremely fast violent stage, usually in a limited area.

Detonation wave.—An explosion wave progressing with a permanent maximum speed with reference to the mass of the detonating substances or gaseous mixtures; in other words, without reference

when wave is commencing with coal dust.

Detonator.—A means of exploding a quick-acting explosive like dynamite; a copper shell containing mercury fulminate, ignited by a fuse or by an electrically heated bridge.

Double-entry zone test.—A test in which coal dust is placed in each of two connected parallel entries.

Dust cloud.—Coal or other dust particles carried in suspension in the air by currents and eddies.

Dustless zone.—A section of the mine entry from which dust has been removed as completely as possible by scraping or sweeping, aided by a compressed-air blast.

Explosibility curves.—Curve lines drawn through coordinating points, indicating ignition or propagation, in which the rectilinear coordinates of the diagram are factors of volatile fixed carbon ratios, total incombustible, density of dust, size of dust particles, and fire damp, if any, in the air current.

Explosibility limit.—The addition of inert dust to coal dust decreases its explosibility, and when enough has been added an explosion can not occur. The point at which explosion can not occur is said to be the explosibility limit of the coal in question.

Explosion.—A rapid oxidation, accompanied by heat and flame, of fire damp, coal dust, or other strongly inflammable material, resulting in a great and sudden development of gases and pressure; when in a mine passage it may become increasingly violent as it progresses in either direction, depending on a continuance of the gas or dust. The term "explosion" as used in the experimental-mine coal-dust and gas tests embraces the phenomena from the time of ignition and relatively slow combustion to the most rapid and violent detonation; it comprehends the combustion zone or moving locus of flaming gases, the gas pressures resulting therefrom, and the successive violent air and gas waves sent in either direction.

Explosion wave.—Strictly speaking, a detonation wave, but as used in this report it includes the progressing wave of any explosion as defined in the preceding paragraph.

Explosion-hazard investigation.—The investigation of a mine to determine the possibility of an explosion occurring by reason of the kind, size, purity, and dryness of the coal dust along the mine passages and the presence or absence of fire damp. It also determines the degree of the hazard of an explosion from natural conditions and of one arising through the neglect or ignorance of the mine personnel. The purpose of such investigations is to make specific recommendations for reducing that hazard to a negligible point by appropriate methods and continued diligence.

Field investigation in reference to experimental-mine tests.—The investigation made at a mine when a large sample is taken for testing at the experimental mine, this investigation including the taking of road dust, rib dust, mine air, and standard coal samples and the noting of conditions affecting the safety of the mine.

Flame recorder.—Synonymous with photographic-paper recorder.

Float dust.—The very fine dust which does not settle out of the air current in the pulverizing machinery but is strained out of the air by fine-cloth bags. This term is also used to designate the fine dust collecting on the roof and timbers in any mine.

Gallery.—A tube of wood or steel in which the earlier work on coal-dust explosions was done in a number of countries. The gallery used by the Bureau of Mines in its work was of steel, 6 feet 4 inches in diameter and 100 feet long. The original British coal-dust tests at Altofts were carried out in a gallery of larger diameter and much longer; the later gallery at Eskmeals has a smaller diameter. The gallery sizes differ in the different countries.

Gas.—In coal-mining practice, usually methane or fire damp. In the experimental mine it means the "natural gas" (see p. 175 for analysis) used in testing.

Gas samples.—Samples of air or gas taken in the mine, of two classes: (1) Samples of gas taken during the progress of an explosion by the automatic samplers; (2) samples of air and gas taken during the preparation of a test using gas in the air current.

Igniting shot.—The blown-out shot, either from a cannon or from a hole drilled in the coal, used to initiate coal-dust explosions in the experimental mine. In standardized tests a cannon is always used to obtain a uniform starting impulse.

Ignition.—As used in the report, the kindling of an explosion of coal dust or gas by shot or flame or an electric arc, usually the first. In standard ignition tests in the experimental mine "ignition" occurs when the flame travels to the end of the dust zones. If the flame stops short of the end of the zone, ignition is not obtained (see p. 62).

Ignition test.—See Standard ignition test.

Ignition zone.—The name given in standard propagation tests to the space from E 1256 to the face of the entry. This space, all inby the last cut-through, is loaded with pure pulverized Pittsburgh coal dust in propagation tests. The term has also been used to designate longer zones in tests made before the standard ignition zone was decided upon.

Inby.—In a direction toward the face of the entry from the point indicated as the base or starting point.

Incombustible matter in dust.—The material in dust which will not burn under any condition. In analysis this is usually reported as moisture and ash.

Inert dust.—Any dust which contains only a small amount of combustible material. In this bulletin roof shale containing 9 per cent of combustible material is classed as inert dust.

Limestone dust.—Dust prepared by grinding limestone. In this bulletin the limestone dust referred to is that normally sold for the purpose of improving farm lands.

Limiting mixture.—The mixture of coal and rock dusts that will not permit the propagation of an explosion.

Loading dust.—The coal dust or mixed dust placed in the mine preparatory to an explosion test.

Main entry of experimental mine.—The right-hand or west passage of the pair of main passageways.

Manometer.—An instrument designed to give a continuous record of the pressure of an explosion at the point where the instrument is located. Manometers are placed in the mine in the instrument stations and are described in detail on page 49.

Maximum-pressure gage.—An instrument for registering the maximum pressure occurring during an explosion at the point where the instrument is located.

Mixed dust.—Dust prepared for testing in the mine by mixing coal dust and inert dust in predetermined proportions. The mixture may also contain water, and different sizes of coal dust may be mixed to produce some desired intermediate size.

Natural gas.—The natural gas at the experimental mine. It consists mainly of 85 per cent methane and 9 per cent ethane. A complete analysis is given on page 175.

Outby.—In a direction toward the mouth of the entry from the point indicated as the base or starting point.

Photographic-paper recorder.—A small device for registering photographically the passage of flame. This must not be confused with the photographing of the flame on the manometer record.

Pioneering wave.—Synonymous with advance wave. This term is used in British reports of coal-dust explosions.

Pit shale.—The name given to the shale from a drift opened in the side of the ravine at a level 62 feet below that of the Pittsburgh coal seam (see p. 150 for analysis).

Pittsburgh bed.—The Pittsburgh coal which outcrops prominently in the vicinity of Pittsburgh and extends under a large area of western Pennsylvania and northern West Virginia. It belongs in the Carboniferous system, Pennsylvanian series, at the base of the Monongahela formation. At the experimental mine the bed is 5½ feet thick; above it is a soft clay band ("draw slate") 8 to 10 inches thick, over which is an impure coal and shale that forms the immediate roof of the mine excavations. The Pittsburgh coal in the vicinity of the experimental mine is termed a "gas coal."

Pressure wave.—A pressure produced by expanding gases moving at high velocity, the side component of which, equivalent to static pressure, may be recorded by a manometer at the side of the entry or mine passage.

Propagation.—In general, propagation is said to occur when the flame of an explosion travels over considerable areas of a mine in such manner as might result in loss of life were men in the mine. In standard propagation tests, propagation is said to occur when the flame travels to the end of the prepared dust zones. If the flame stops short of the end of the zone, propagation is not obtained.

Propagation test.—See Standard propagation test.

Pulverized dust.—Dust of which 95 to 98 per cent will pass a 100-mesh screen and of which 75 to 95 per cent will pass a 200-mesh screen, the intermediate size depending on the hardness of the material used. Pulverized Pittsburgh coal dust will run 75 to 85 per cent through 200-mesh.

Reflected wave.—A (gaseous) pressure wave resulting from a direct wave striking an obstacle or an opposing surface and being reflected backwards.

Retonation wave.—A wave passing back through burned or burning explosion gases toward the origin, at the rate of a sound wave through gases of like temperature, from a point in the explosion wave, usually of high pressure, to an area of lower pressure.

Rib dust.—Dust found on the side walls of a mine. The dust from the roof is generally included with this sample.

Road dust.—Dust found on the floor of a mine entry.

Rock dust.—The general name for any kind of inert dust used in rendering coal dust inert or in filling rock-dust barriers. Equivalent to the British "stone dust."

Rock-dust barrier.—A device which releases a large quantity of inert dust in the air in the path of an explosion, extinguishing the flame. Various types are described in Chapter IX, and in Part 4 of this appendix (p. 567).

Rock-dust zone.—A section of a mine entry the ribs, roof, and floor of which have been coated with rock dust.

Rock dusting.—The application of rock dust to the surfaces of a mine entry to prevent the passage of an explosion.

Roof shale.—The layer or seam of shale occurring immediately above the Pittsburgh coal seam. This shale or slate has to be taken down in mining operations. When ground it has been used at the experimental mine for mixing with coal dust and for filling rock-dust barriers.

Sampler (gas).—An instrument designed to take samples of the flame or other explosion gases at predetermined intervals during an explosion. These are described in detail on page 52.

in this bulletin the term refers primarily either to ground draw shale, known as "roof shale," or to material taken from a pit 62 feet below the level of the Pittsburgh coal seam, this latter material being termed "pit shale."

Shock wave.—The wave sent out through the air by the discharge of the shot initiating an explosion. This wave travels with the velocity of sound and produces to the human ear the noise like the "boom of a cannon."

Shot.—A charge of some kind of explosive, in regular mining placed in a hole drilled in the coal, the purpose being to break down the coal. In this bulletin the word refers to the blown-out shot from the cannon unless the text indicates otherwise.

Side shelves.—The shelves fastened along the sides of the entry throughout the explosion zone on which dust is placed in explosion testing. There are five shelves on each side of the entry, vertically above one another. They consist of 3 by 4 inch timbers fastened to heavy posts recessed into the rib by bolts.

Single-entry zone test.—A test in which coal dust is placed only in a single entry.

Sound wave.—Sometimes used interchangeably with "shock wave;" technically, a wave motion in the air which affects the human ear as sound. Owing to the reflection of waves from the various surfaces, the sound is more or less prolonged, and as it reaches a given point is really a series of vibrations.

Standard ignition test.—A method developed for testing coal dust to obtain the limits of explosibility (see p. 179).

Standard Pittsburgh coal dust.—Coal dust from the Pittsburgh bed at the experimental mine pulverized so that over 95 per cent will pass 100-mesh and from 75 to 85 per cent will pass 200-mesh.

Standard propagation test.—A method developed for testing coal dust to obtain the limits of explosibility (see p. 180).

Station.—The name given to the reinforced concrete chambers prepared in the experimental mine for holding instruments and protecting them from damage during explosion tests.

Superdusting.—The presence of a very large excess of coal dust in the air over that required for consumption of the oxygen.

Test zone.—The section of the mine loaded with coal dust for a given explosion test. It is most frequently used in connection with the zone from E 1300 to E 950 and E 1250 to A 950, used in the standard ignition and propagation tests.

Tin-foil.—A strip of metallic tin 0.0004-inch thick, placed over two brass posts set about three-quarters of an inch apart in a wooden block, the use being to register the passage of flame through melting

and thus breaking an electric circuit. The foil and posts are set in a shallow groove in the block (see p. 40).

Transverse shelves.—Synonymous with cross shelves.

Twenty-mesh dust.—Dust at least 95 per cent of which will pass through a 20-mesh sieve.

Wet dust.—Dust which has been mixed with moisture or which has become wet from water in the mine. The source of the water usually is given or is evident from the text.

Zone.—That portion of the mine entry devoted to some particular dust mixture in preparing for an explosion test. It is generally modified by an adjective showing the kind of dust as "mixed-dust zone," "Pittsburgh coal-dust zone," "rock-dust zone," etc.

PART 2.—FORMS FOR REPORTING THE DETAILS OF AN EXPLOSION TEST AT THE EXPERIMENTAL MINE.

Testing on such a large scale as that at the experimental mine involves a large amount of routine detail and the work of a considerable number of men. It was realized from the beginning that it was necessary to keep a careful record of all factors which might affect an explosion and to note all the conditions after an explosion occurred. A report giving all the details of each test was prepared immediately after each explosion. As the testing progressed the form of these reports was revised from time to time in order to include all information in a clear and logical form with the least amount of work. To illustrate the method used, the report of test 105 is given below. This report as presented here differs from the original in that the information has been rearranged according to the revised form in use at the time of writing and in that symbols and abbreviations which might be confusing have been written out in full. Test 105 has been referred to on page 73 and the instrument-record curve sheet embodying the results of the test is given as figure 10. The test was made notable by the presence of the distinguished French coal-dust investigator, J. Taffanel.

EXPERIMENTAL MINE EXPLOSION TEST NO. 105.

(April 18, 1914.)

Observers.—Messrs. Rice, Taffanel, Paul, Jones, Howarth, Clement, Egy, Rinehart Greenwald, and miners.

Purpose.—To obtain records in the entry and air course of the explosion of a double-entry zone of pulverized Pittsburgh coal dust; to test the efficiency of a concentrated type A barrier and a type A box barrier.

Igniting shot.—Blown-out shot from cannon at E 1304, loaded with 4 pounds of FFF black powder and 3 pounds of slightly damp clay stemming. The charge was prepared by Jones and the cannon was loaded by Jones and Wallace.

552 COAL-DUST EXPLOSION TESTS IN EXPERIMENTAL MINE.

Test zone.—Pittsburgh coal dust pulverized from coal mined in No. 1 room, off No. 1 left butt.

Zone. —E 1300 to E 800.....	Feet 500
E 1250 to A 800.....	500

Total	1,000
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Rate of loading.—Two pounds per linear foot of entry.

Total loading. —1,000×2.....	Pounds. 2,000
Platform before cannon.....	525

Total	2,025
--------------------	-------

Sizing.—Dust from platform before cannon:

100.0 per cent through 100-mesh.

99.8 per cent through 200-mesh.

96.4 per cent through 240-mesh.

Dust from side shelves:

100.0 per cent through 100-mesh.

95.0 per cent through 200-mesh.

94.0 per cent through 240-mesh.

Samples.—Can 23,109, taken from platform.

Can 23,059, taken from E 1300 to E 810.

Can 23,305, taken from E 1250 to A 800.

Barriers.—E 805 to E 790: Concentrated barrier having two boxes each 7 feet long and 7 feet wide. The bumping vane was located at E 814. The operating vane was located at E 900, 90.5 feet in advance of the inby tripping lever and 95 feet in advance of the inby edge of the inby box. This barrier was loaded with limestone dust.

A 800 to A 770: Four-box type A barrier. The distance from the bottom of the boxes to the top of the bolts from which the hooks hang is 16 inches. Boxes while empty were pushed off their supports and worked easily and accurately, a movement of 1 to 1½ inches pushing the hooks off the supports. This barrier was loaded with crushed roof-shale dust.

A 470 to A 414: Ten Taffanel shelves loaded with crushed roof-shale dust.

Auxiliary zone.—Auxiliary zones of pulverized Pittsburgh coal dust were prepared outby the first two barriers in order to make the test of their efficiency more severe.

Zone outby concentrated barrier.

E 800 to E 470, a distance of 330 feet, loaded at the rate of 2 pounds per foot.

Total loading, 660 pounds.

Zone outby box barrier.

A 800 to A 470, a distance of 330 feet, loaded at the rate of 2 pounds per foot.

Total loading, 660 pounds.

Ventilation.—The air course opening was not closed, so there was no air movement in the test zone.

Sample bottle 72 taken at face before firing.

Humidity.

Station.	Wet bulb.	Dry bulb.	Relative humidity.
	° F.	° F.	Per cent.
A 250.....	51	52½	91
A 850.....	49½	51	90
E 1300.....	50½	51½	94
E 1246.....	50½	51½	94
E 800.....	50½	51½	94
E 450.....	50½	51½	94

[Readings were taken with the sling psychrometer.]

Barometer.—28.93 inches at observatory.

CONDITION OF THE MINE.

Cleaning.—The mine entry was cleaned of all loose dust in the test zone; that is, from the face of the entry to E 800 and A 800. There was some old dust, principally rock dust, left from A 770 to A 464 and from A 330 to A 250.

Moisture.—The floor from the face of the entry to E 1060 was damp, the ribs and roof being damp to E 1250, then dry to E 1150, and then damp to E 1060. From E 1060 to E 940 the entry was wet, with the exception of E 997 to E 970, which was only slightly damp. From E 940 to E 725 the floor was damp and the roof and ribs dry. From E 725 to E 350 the floor was damp, there being some water standing in the ditch from E 725 to E 550. The roof and ribs were dry. The entry surfaces were wet and sticky from E 350 to the pit mouth.

The cut-through floor was damp and the roof and ribs were dry. The floor of the air course was damp from A 1250 to the barrier at A 800. The ribs and roof were dry to A 1050; from this point to the barrier the sides were dry and the roof slightly damp. From A 770 to A 330 the floor was damp, the sides were slightly damp, and the roof was damp. From A 330 to the pit mouth the ribs and roof were damp and the floor was dry.

Instruments.—B. C. D. manometers at E 950, E 750, and A 950; French manometers at E 1150 and A 1150; shock-wave circuit breakers at E 1150, E 950, E 750, E 550, and E 350; tin-foils wired at E 1150, E 1050, E 950, E 850, E 750, E 650, E 550, E 350, A 1150, A 1050, A 950, and A 750; trolley, E 550 to E 450; air-direction indicator at E 750; concentrated barrier; operating vane, bumping vane, and box wired to record; box No. 1 in air course wired to record.

OUTSIDE MANIFESTATIONS.

Time of shot.—The shot was fired at 3.30 p. m.

Violence of explosion.—The explosion was not violent, but of moderate pressure, sustained through several seconds. The explosion came out the main opening at least a second in advance of issuing from the air course. There was a sound of wood fragments raining down the side of the hill. The shaft doors were blown open. One plate from the explosion door was blown 20 feet east. There were five puffs of smoke from the air shaft, with intervals of inrush between. An observer looked down the shaft and counted five more reversals after the last puff visible at surface. Two hinges from the concentrated barrier were found 50 feet north of the pit mouth.

INSIDE OBSERVATIONS.

Flame data.—The following table gives the condition of the guncottons, matches and tin-foils after the test.

Location.	Guncotton.	Match.	Tin-foil.
E 625....	Unburned ..	Unburned ..	Unburned.
E 650....	Burned	do.	
E 675....	do.	do.	
E 700....	do.	do.	
E 725....	do.	Burned	Burned.
E 750....	do.	do.	
E 775....	do.	Unburned ..	
E 800....	do.	Burned	
IRB 25....	do.	do.	Burned.
IRB 50....	Unburned ..	do.	
A 1275....	Burned	Burned	
A 1300....	do.	Unburned ..	
A 825....	do.	Burned	
A 800....	do.	do.	
A 775....	do.	Unburned ..	
A 750....	do.	do.	
A 725....	do.	Broken	
A 700....	Broken	do.	
A 675....	Unburned ..	Unburned ..	
A 650....	Burned	do.	
A 625....	Unburned ..	do.	
A 600....	Burned	do.	
A 575....	Unburned ..	do.	

Length of flame.—The flame extended out to and including the following point:

Guncotton.	Matches.	Tin-foil.
E 650....	E 725....	E 750....
A 600....	A 800....	A 750....

Exceptions to this are the A 675 and A 625 guncottons, unburned, and the E 775 match, unburned.

The flame also traveled 25 feet into 1 right butt, 25 feet toward the face of the air course, throughout both left butts, and into the rooms.

Violence.—Fragments of the concentrated barrier were found in the entry, beginning at E 100 and extending as far as E 640. These varied from small pieces to sections of 8 by 8 inch timber, 5 or 6 feet long. Limestone from the barrier was first noted at E 260. At E 315 a sample of dust was taken from the dust covering a large barrier timber. At E 640 was a bolt and wire from the vane at E 900. At E 750 the vane of the air-direction indicator was bent outby. Four side shelves were broken between E 750 and E 775. The inby set of supporting timbers was all that remained of the concentrated barrier at E 800. The bumping vane and block at E 814 were not damaged. The side shelf was broken at E 846. The operating vane and the east supports at E 900 were gone. No damage was done from this point to the corner of No. 2 left butt and the air course. The west rib opposite No. 2 butt was plastered with dirt. Some broken wood was found along the rib. At 2B 15; a post was pulled out of its recess in the rib. A post from north rib at 2B 94 was found at 2B 28. At 2B 107 the side shelves were broken from the post. From this point to 2B 166 the posts on both sides were torn out of the rib, falling to the floor, with side shelves attached. One set of shelves in the cut-through to No. 1 left butt was thrown down. The compressed-air line was broken at 1B 200. At 1B 145, 1B 130, and 1B 104 posts were pulled from the south rib. At 1B 113 a post was pulled from the north rib. Side shelves on the south rib at 1B 100 were torn out. In No. 1 room two posts were blown

raised and the ballast scattered. In the neck of No. 2 room the track on the outside of the curve was raised up.

At 1B 90 a post with side shelves attached was lying on the floor. At 1B 72 a post was torn out of north rib. Shelves attached prevented its falling over. At 1B 71 was a post with shelves attached, thrown from 1B 80. At 1B 53 was a post from 1B 71. The shelves were scattered in between. At 1B 40 a post with shelves was moved outby 6 feet. At 1B 25 there were two posts lying on floor, one from the neck of No. 2 room, the other from the south rib at 1B 55. On the air course, at the junction of No. 1 butt, was a pile of posts, shelves, broken wood, and dirt thrown out of No. 1 butt. A post which had been lying along the rib at No. 1 room was at A 838. Nothing was left of the box barrier at A 800. A post was found across the track at A 750. A post and shelves from A 703 was thrown out to A 450. Broken wood from the barriers was scattered from A 350 to A 50.

Coke data.—No coke was found in the entry outby E 835. From E 835 to E 1250 coked dust occurred on the outby exposures of the roof, posts, nuts holding side shelves, and on the projections at the instrument stations. At E 835 there was only a little scattered coke, but the quantity increased to crusts one-eighth inch thick at E 1030. Some large crusts occurred at E 1217, and a little coke on the platform in front of the cannon. In the cut-through there was coke on the air course exposure of posts in the north rib at C. T. 20 and C. T. 41. There was a coke crust on the entry exposure of a post in the south rib at C. T. 41. There were coke bubbles on both ribs of the stub entry. From the corner of the 1250 cut-through to A 1260 were heavy crusts on the outby exposures of the posts and shelves. From A 1246 to A 918 there was coked dust on the inby exposures of the roof, posts, nuts holding side shelves, and the projections at the instrument stations. This was heaviest near A 1200 and A 1090. Coke also occurred on the outby exposures at the following points: A 1160, on concrete of station; A 1105, on post at west rib; A 1090, a heavy crust on post at west rib; A 1080, on east rib; A 1073, on rib; A 1050, on post at west rib; A 927, on post at west rib. There was also some coke on the air course exposure of the north rib in the 1050 cut-through.

In No. 2 butt there was a little coke on a post at 2B 15, on the inby roof exposure at 2B 28, and on top of a post at 2B 44. From 2B 62 to 2B 103 there was a little coke on the inby side of the post, those near 2B 103 having more than those outby. The 100 cut-through to No. 1 butt was blistered on both ribs from No. 2 butt to the stopping. From 2B 118 to 2B 166 the ribs, roof, and posts were heavily crusted with coke on the inby exposures. The west rib was blistered at 2B 166. There was coke on the inby exposures from 2B 166 to the 200 cut-through, but in smaller amounts. The south rib, opposite and somewhat outby the 200 cut-through to No. 1 butt, had coked-dust masses in the crevices and ledges. There were a few bubbles on the side shelves. In the 200 cut-through there was coke dust on the exposures of the roof, ribs, and posts toward No. 1 butt. The west rib was blistered 10 feet and 25 feet from No. 1 butt. In No. 1 butt the rib opposite the 200 cut-through was heavily blistered, the roof showed coking, and there was coked dust on all north exposures. From this point to the face of No. 1 butt the north rib was blistered. The face was blistered and had a few coke bubbles. There was globular coke and porous masses on the floor. The southeast corner of the cut-through was heavily blistered and coked in places.

Coking and blistering decreased from the cut-through to 1B 190. From 1B 190 to 1B 165 there was no coking or blistering. Blistering began again at 1B 165, and increased to 1B 145. At 1B 145 a post at the south rib had coke globules on the outby sides. At 1B 120 the south rib was plastered with coked dust. The side of the shelves was likewise plastered from 1B 115 to 1B 124, with some masses on top of the shelves. At 1B 114 there was a $\frac{1}{2}$ -inch coked-dust crust on the outby side of a post.

In No. 1 room neck the west rib was blistered and the east rib was plastered with dirt. There was a little coked dust on inby exposures and dirt on the outby exposures. Both ribs of the room were blistered, beginning at the neck and decreasing inby, blistering ceasing on the west rib at 1R 49 and on the east rib at 1B 80. There were coke-dust globules on the inby exposures of the ribs, roof, and posts as far as 1B 80, decreasing in amount from the room neck inby. The outby exposures of the posts also had a few bubbles and there were a few on the outby side of ribs and roof at 1B 60. The south rib of the room cut-through to No. 2 room was blistered and coated on the exposure toward No. 2 room with coke. The north rib was blistered and coked in places.

In No. 2 room the west rib was blistered to 2R 40, and the east rib was heavily blistered as far as 2R 55. There were porous masses of coke on the gob as far as 2R 40. The posts as far as 2R 66 had coke on them. Near the room neck the coke was mainly toward the cut-through from No. 1 room. Inby it was on all sides of the posts, but was heavier on the side toward the face. The amount decreased from the room neck inby. The ribs and roof had coke on many inby exposures and a little on some outby exposures.

On No. 1 butt at 1B 94 the south rib was blistered. The south rib at 1B 94 and 1B 84 had coke on the inby exposures. There was coked dust on inby exposures to 1B 72 as well as blistered patches, but there was no coke on No. 1 butt outby 1B 72 or on the air course outby A 850.

ANALYSES OF DUST SAMPLES.

After the explosion samples of road dust were taken. Can 23070 was taken at E 800; can 22966 was taken at E 750; can 23211 was taken at E 550; bottle was taken at E 315; coke-dust sample was taken at 1B 104.

REMARKS.

The barriers were successful, the coal-dust zones outby not being ignited. This explosion did considerable damage in the butt entries.

A specimen analysis sheet used by the Bureau of Mines, additional analyses of samples collected, and an instrument record sheet for test 105 follow.

DEPARTMENT OF THE INTERIOR.

BUREAU OF MINES.

COAL-ANALYSIS REPORT.

Test No. 105.

Lab. No. 19214

Sample of Coal dust.

Can No. 23109

Operator Mine: Experimental.

State: Pa.; County Bed

Town: 1 mile south of Bruceton.

Location in mine: Platform in front of cannon before test.

Method of sampling: Grab. Gross weight, lbs. Net weight, gm., 154.5.

Date of sampling: 4-18-14. Date of Lab. sampling: 4-24-14. Date of analysis: 5-6-14.

For B. of M. section: G. S. Rice. Collector: L. M. Jones.

AIR-DRY LOSS (1.6).		COAL. (Air dried.)	COAL. (As re- ceived.)	COAL. (Moisture free.)	COAL. (Moisture and ash free.)
Proximate Analysis.	Moisture.....	1. 26	2. 79	.....	.....
	Volatile matter.....	33. 59	33. 07	34. 02	37. 38
	Fixed carbon.....	56. 27	55. 40	56. 99	62. 62
	Ash.....	8. 88	8. 74	8. 99	.....
		100. 00	100. 00	100. 00	100. 00
Ultimate Analysis	Hydrogen.....				
	Carbon.....				
	Nitrogen.....				
	Oxygen.....				
	Sulphur.....				
	Ash.....				
Calorific value determined	Calories.....				
	British thermal units.....				
Calorific value calculated from ultimate analysis	Calories.....				
	British thermal units.....				

Date, May 19, 1914.

(Signed)

A. C. FIELDNER, *Chemist.*

* This form is printed on sheets 8 by 10½ inches.

ADDITIONAL COAL ANALYSES.

SAMPLE OF COAL DUST BEFORE TEST.

Sample, coal dust; laboratory number, 19,215; can number, 23,305; location in mine, E 1250 to A 800 (before test); method of sampling, grab; net weight, 565.5 grams; date of sampling, April 18, 1914; date of laboratory sampling, April 24, 1914; date of analysis, May 6, 1914.

Proximate analysis.

Air-dry loss (1.4).	Air dried.	As received.	Moisture free.	Moisture and ash free.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Moisture.....	1.34	2.68		
Volatile matter.....	25.96	35.47	36.45	39.15
Fixed carbon.....	55.90	55.14	56.66	60.85
Ash.....	6.80	6.71	6.89	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF COAL DUST BEFORE TEST.

Sample, coal dust; laboratory number, 19,308; can number, 23,059; location in mine, E 1300 to E 810 (before test); method of sampling, grab; net weight, 557.5 grams; date of sampling, April 18, 1914; date of laboratory sampling, May 5, 1914; date of analysis, May 11, 1914.

Proximate analysis.

Air-dry loss (0.9).	Air dried.	As received.	Moisture free.	Moisture and ash free.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Moisture.....	1.71	2.59		
Volatile matter.....	36.09	35.77	36.72	39.30
Fixed carbon.....	55.75	55.25	56.72	60.70
Ash.....	6.45	6.39	6.56	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF ROAD DUST AFTER TEST.

Sample, road dust; laboratory sample, 19,312; can number, 22,966; location in mine, E 750 (after test); method of sampling, grab; net weight, 464.2 grams; date of sampling, April 18, 1914; date of laboratory sampling, May 6, 1914; date of analysis, May 12, 1914.

Proximate Analysis.

[Over 20-mesh, 25.75 per cent rejected; through 20-mesh, 74.25 per cent analyzed.]

Air-dry loss (2.0).	Air dried.	As received.	Moisture free.	Moisture and ash free.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Moisture.....	1.72	3.71		
Volatile matter.....	26.58	26.04	27.04	46.16
Fixed carbon.....	31.0	30.37	31.54	53.54
Ash.....	40.7	39.88	41.42	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF ROAD DUST AFTER TEST.

Sample, road dust; laboratory sample, 19,313; can number, 23,070; location in mine, E 800 (after test); method of sampling, grab; net weight, 530.4 grams; date of sampling, April 18, 1914; date of laboratory sampling, May 6, 1914; date of analysis, May 12, 1914.

Proximate Analysis.

[Over 20-mesh, 21.12 per cent rejected; through 20-mesh, 78.88 per cent analyzed.]

Air-dry loss (2.4).	Air dried.	As re- ceived.	Moisture free.	Moisture and ash free.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture.....	1.69	4.04		
Volatile matter.....	25.16	25.56	25.59	44.96
Fixed carbon.....	30.92	30.18	31.45	55.14
Ash.....	42.23	41.22	42.96	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF ROAD DUST AFTER TEST.

Sample, road dust; laboratory number, 19,314; can number, 23,211; location in mine, E 550 (after test); net weight, 651.4 grams; method of sampling, grab; date of sampling, April 18, 1914; date of laboratory sampling, May 6, 1914.

Proximate Analysis.

[Over 20-mesh, 28.68 per cent rejected; through 20-mesh, 71.32 per cent analyzed.]

Air-dry loss (2.6).	Air dried.	As re- ceived.	Moisture free.	Moisture and ash free.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture.....	0.70	3.32		
Volatile matter.....	35.30	34.37	35.55	75.16
Fixed carbon.....	11.67	11.36	11.75	24.84
Ash.....	52.33	50.95	52.70	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF ROAD DUST AFTER TEST.

Sample, road dust; laboratory number, 19,326; can number, bottle; location in mine, E 315 (after test); method of sampling, grab; net weight, 88.9 grams; date of sampling, April 18, 1914; date of laboratory sampling, May 7, 1914.

Proximate Analysis.

[Over 20-mesh, 33.16 per cent rejected; through 20-mesh, 66.84 per cent analyzed.]

Air-dry loss (2.6).	Air dried.	As re- ceived.	Moisture free.	Moisture and ash free.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture.....	0.68	3.25		
Volatile matter.....	34.47	33.58	34.71	76.79
Fixed carbon.....	10.42	10.15	10.49	23.21
Ash.....	54.43	53.02	54.80	
Total.....	100.00	100.00	100.00	100.00

SAMPLE OF COKED DUST AFTER TEST.

Sample, coke dust; laboratory number, 19,324; can number, bottle; location, inby side of post, south rib 1B 104 (after test); net weight, 26.6 grams; date of sampling, April 18, 1914; date of laboratory sampling, May 6, 1914; date of analysis, June 3, 1914.

Proximate Analysis.

Air-dry loss (0.6).	Air dried.	As re- ceived.	Moisture free.	Moisture and ash free.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture.....	2.01	2.56		
Volatile matter.....	18.24	18.14	18.62	23.66
Fixed carbon.....	45.42	45.16	46.34	71.34
Ash.....	31.33	34.14	35.04	
Total.....	100.00	100.00	100.00	100.00

* Not all combustible "volatile" but water of crystallization, etc.

FORM FOR PRELIMINARY REPORT OF INSTRUMENTS.

DEPARTMENT OF THE INTERIOR,

BUREAU OF MINES.

EXPERIMENTAL MINE.

Test No. 105.

APRIL 18, 1914.

PRELIMINARY REPORT OF INSTRUMENTS.^a

STATIONS.	PRESSURE RECORD.		FLAME RECORD.			SHOCK WAVE.			Air-direction Indicator. At E 750.	
	Instru- ment.	Maximum pressure.	Operated.	Time.	Velocity.	Operated.	Time.	Velocity.	To face..	Off.....To mouth
Ignition at—										
E 1300.....			Yes.....	0. 000		Yes.....	0. 000			
E 1250.....										
E 1150.....	French 1	34	Yes.....	0. 682	1136	Yes.....	0. 107		1. 11	0. 50
E 1050.....			Yes.....	0. 770	1176			1204	1. 19	1. 13
E 950.....	B. C. D. 200 No. 6	29	Yes.....	0. 855	1850	Yes.....	0. 273		1. 28	1. 24
E 850.....			Yes.....	0. 909				1142	1. 40	1. 31
E 750.....	B. C. D. 200 No. 5	10	Yes.....	1. 021	893	Yes.....	0. 448		1. 45	1. 43
E 650.....			No.....					1130	1. 64	1. 49
E 550.....			No.....			Yes.....	0. 025		1. 60	1. 64
E 450.....								1105		1. 72

E 350	No.	Yes	1075	Switch.	Time.	Velocity.
A 1150	31	Yes	0.696	E 550	1.041	471
A 1050		Yes	0.789	E 450	1.250	
A 950	19	Yes	0.835			
A 750		Yes	1.132			
A 550	No.					
BARRIERS.						
Concentrated barrier, E 800				Box barrier, A 800		
Operating vane, 0.353 second				Box No. 1, 0.880 sec.		
Bumping vane, 0.427 second						
Box, 0.52 second						

^a This form is printed on sheets 8 by 10½ inches.

(Signed) W. L. Egy.

In the table above, the first column gives the name of the station, showing the distance from the mouth of the mine to the station in the entry (E) or the air course (A). The second column gives the kind of instrument and a number designating the particular instrument; "French" means the type of manometer used in the French coal-dust gallery at Liévin; "B. C. D." means the "British Coal Dust" manometer used at the Altofts gallery. The Bureau of Mines manometer, patterned after the French, had not been constructed at the time of test No. 105. The third column gives the maximum pressure shown in the manometer curve. The fourth column states by "yes" or "no" if the tin foil of the respective station had been burned by the explosion flame (or ruptured by force); the fifth column gives the time (in seconds) of the burning out of the tin foil after the ignition shot; the sixth column indicates the calculated velocity of the flame between the respective stations.

The seventh and eighth columns deal with the operation and the time of operation of a circuit breaker of the pressure-plunger type; the ninth column shows the calculated velocity—that of a sound wave—the higher velocity at the first interval E 1150 to E 1050 being due to the mechanical movement of the air column by the cannon shot.

The tenth, eleventh, and twelfth columns relate to the movement of the air-direction instrument at E 750; the column headed "face" indicates movement toward the face; none shown in this test, although there probably was air movement toward the face, but too feeble to move the indicator to make the electrical contact. The column headed "off" means no movement, and the column headed "mouth" means that the air-direction vane was deflected outward strongly enough to make the electrical contact. The first outby movement of the air-direction indicator was at 0.500 second, or only 0.052 second after the more sensitive shock wave recorder operated at that station, and 0.521 second before the flame reached that station. Seemingly the shock wave caused the operation of the concentrated barrier vane, which in turn caused the barrier at station E 800 to drop at 0.520 second, or 0.445 second before the flame reached the barrier, the drop of which extinguished it.

On the other hand, the box barrier in the air course at A 800, which had no advance vane, did not operate till a moment before the arrival of the flame; nevertheless its operation was successful in extinguishing flame.

The records of the "trolley" between E 550 and E 450 indicate that the column of air driven ahead of the explosive wave was moving

at the rate of nearly 300 feet per second, or 300 miles per hour. If an explosion wave moved through this column of air at the same velocity, it would give a velocity of about 1,600 feet per second, which is comparable with the figure obtained for the flame (1,850 feet) at the time of extinguishment by the conflagration barrier.

PART 3.—EFFECT OF LIMESTONE DUST ON THE COMBUSTION OF COAL DUST.

By ALAN LEIGHTON.

INTRODUCTION.

Mr. L. G. Hill says, in the Proceedings of the South Wales Association of Mining Engineers, November 26, 1917, that limestone has been used to maintain combustion or decomposition, as is shown in the common practice of burning limestone into lime with fuel of low calorific quality. He also claims that limestone dust blown into the flame of a Bunsen burner considerably increased the volume of flame, which thereby implies that a dust cloud consisting of mixtures of limestone would be as inflammable, and possibly more inflammable than a cloud of pure coal dust.

This problem is of immediate importance because of the use of limestone for rock-dusting coal mines in order to prevent possible explosions. If limestone assists the combustion of coal under the condition of an explosion, its use in mines should be continued at once.

The references given below and the experimental work described herein indicate that limestone does not assist the combustion of coal dust, to any appreciable extent at least.

REFERENCES.

The following references indicate that limestone does not assist its carbon and that whatever action there may be with coal dust is a catalytic one:

A. R. Johnson, writing in the Journal of the American Chemical Society⁶⁰ says:

From the results of either author (Pott and Zavriev) it follows that the dissociation point (i. e., the temperature at which the pressure of carbon dioxide is one atmosphere) is close to 910° C. This value was confirmed by special experiments made by Pott and Zavriev, who determined anew the temperature at which a loss of weight occurred when the carbonate was heated in an atmosphere of pure carbon dioxide. He shows, however, that the possibility of the formation of solid solutions of calcium oxide in calcium carbonate and vice versa is practically excluded, while it was shown by Zavriev that no basic carbonate exists.

⁶⁰ Johnson A. R., The thermal dissociation of calcium carbonate: Jour. Am. Chem. Soc., vol. 40, p. 938.

bonate proceeds according to the scheme $\text{CaCO}_3 = \text{CaO} + \text{CO}_2$, and to that scheme solely.

The Iron and Coal Trades Review,⁵¹ referring to the advantages obtained by adding limestone to the coke ovens, states editorially:

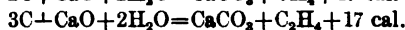
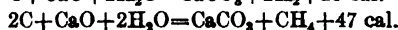
The limestone serves a dual purpose in the retort:

1. It takes up heat and decomposes at a low temperature when in contact with coal having a high oxygen content.

2. On the decomposition of the limestone, the lime is freed from its neutralizing agent, carbon dioxide, and being now in a nascent condition and chemically active, attacks and assists in the heat of carbonization, decomposes the organic matter and bases contained in the coal, thus liberating the gases at a low temperature, usually below 450 degrees centigrade.

The calcium and its catalytic action assists in the combination of O_2 and H_2 forming water and carbon and hydrogen forming hydrocarbons.

Holgate⁵² gives a few interesting reactions in an article in the Gas World:



DISCUSSION.

Apparently limestone dissociates only into carbon dioxide and lime, and free carbon is never liberated even at very high temperatures. From the data available on the coking of coal, it is evident that at comparatively low temperatures free lime may have a catalytic effect, tending to decompose the organic matter and bases contained in the coal and to facilitate the combustion of the carbon.

It may be possible, by using very small quantities (a few per cent) of limestone dust with coal dust, to obtain an accelerated burning. It is certain, however, that with any considerable percentage of limestone, such as would exist in a mine, the cooling action on a burning dust cloud would be considerably greater than any heat that could be liberated by the catalytic action of the limestone. In fact, the effect of this latter reaction would be entirely negligible.

EXPERIMENTS.

Experiments were made by blowing coal dust and coal-dust-limestone mixtures through the flame of a Bunsen burner in order to note, if possible, the differences in the flame produced. Analysis of the limestone used was as follows:

⁵¹ Iron and Coal Trades Review, Low temperature carbonization: vol. 88, October 1, 1915, p. 421.

⁵² Holgate, The coal-liming process at Cheltenham: Gas World, November 1, 1913, p. 583.

H ₂ O.....	.....
CO ₂.....	.....
H (organic).....	.....
C.....	.....
S.....	.....
SO ₃.....	.....
SiO ₂.....	.....
Al ₂ O ₃.....	.....
Fe ₂ O ₃.....	.....
CaO.....	.....
MgO.....	.....
Total.....	.....

The four methods employed follow. None of them seem results agreeing with those obtained by Mr. Hill.

1. Coal dust was loaded into a glass tube and a bulb so attached that when it was compressed the dust would be expelled from the tube. Good flames were produced in this manner by directing the dust through a burner flame, but the force of the puff and the direction of the stream were so difficult to control that accurate comparisons could not be made with the limestone-coal-dust mixtures.

2. The coal dust was poured down a tube whose lower aperture was placed just above a jet of air from the blast, which directed the dust through the burner flame as it issued from the tube. While the coal dust was being blown through the flame, powdered limestone was also blown into the flame from apparatus used in the first tests. The quantity of limestone dust per single puff was varied considerably, but this method did not permit measurement of the relative quantities of coal dust and limestone dust used. It was plainly evident, however, that each cloud of dust temporarily cut down the size of the coal-dust flame.

3. An apparatus shown in the accompanying sketch (fig. 79) set up. The coal dust was loaded into the tube *a*, which opened above the bottom of an iron trough *b*. The dust piled around the opening so that the tube could be filled, but if the dust were re

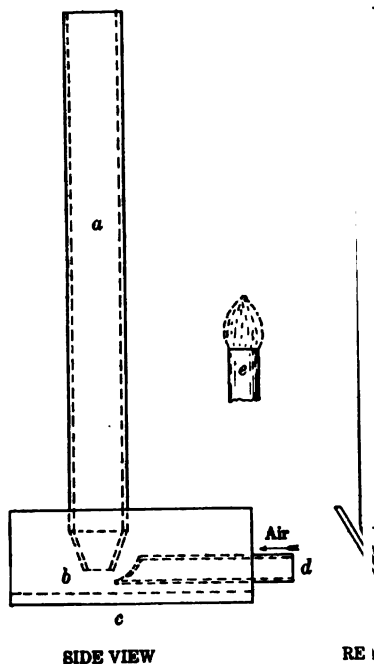


FIGURE 79.—Apparatus for the laboratory determination of the effect of limestone dust on coal dust.

from the trough at the bottom the tube emptied itself by gravity. A jet of air was then directed through the nozzle *d*, underneath the tube *a*, along the trough to the flame. As the jet moved it blew the dust from underneath the tube and a steady stream of dust was obtained. It was evident that the flame produced, after the tube had been about half emptied, was longer and larger in diameter than that first obtained, probably because the air jet was not overburdened with dust at this time.

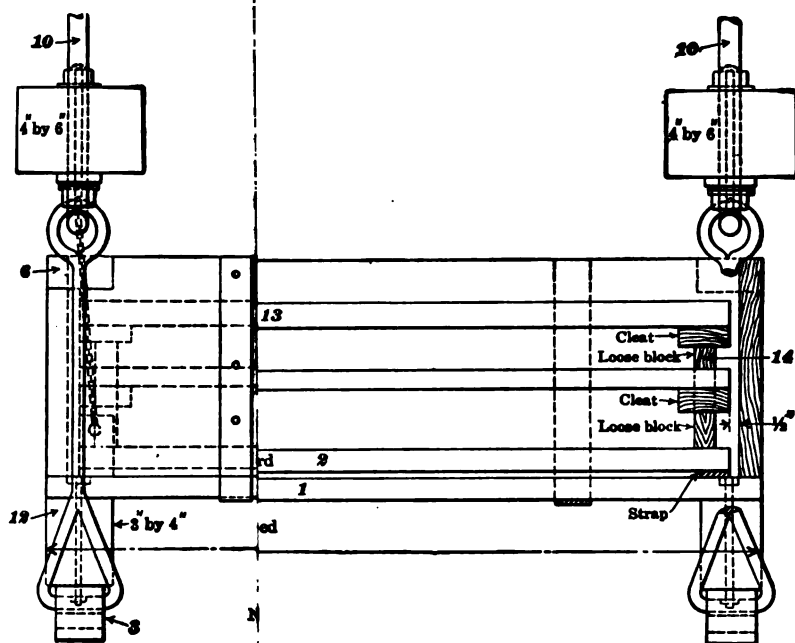
This tube was loaded several times with coal dust in the bottom and a mixture of approximately 10 per cent of limestone and 90 per cent of coal dust in the upper part of the tube. As the stream of dust issued there was no noticeable effect when one zone was changed for the other. However, when the loading was so made that the limestone mixture was on the bottom and the coal dust on top, as soon as the coal zone was reached the size of the flame increased greatly; thus it was evident that the limestone prevented the flame from increasing as the quantity in tube *a* decreased.

4. The previous experiments were conducted with a dust stream of sufficient density to ignite and burn throughout its length. Mr. Hill mentions a display of bright sparks. It is possible that he used a cloud which was not dense enough to ignite and permit the flame to extend out into the cloud. It was found that by blowing up little piles of coal dust into the air around the burner the flame was at once very luminous and full of sparks, but did not usually travel through the cloud. This procedure was tried with piles of pure coal dust and a mixture of 10 per cent of limestone and 90 per cent of coal dust. The cloud of dust from the pure coal frequently ignited.

In six or seven trials the dust cloud from the limestone-coal-dust mixture ignited but once. It seemed that the burner flame in the dust mixture was at times more luminous than the flame obtained in a similar manner from a coal-dust cloud. Similarly, when the pure limestone was blown into the burner it gave a strong sodium flame. It is possible that such an optical effect might lead one to believe that limestone dust was inflammable.

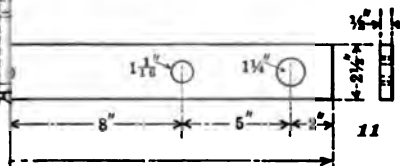
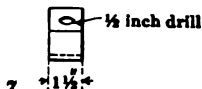
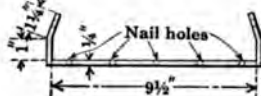
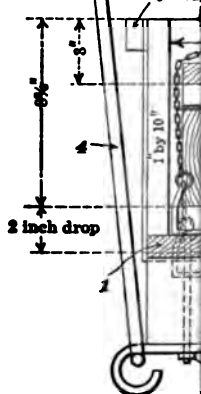
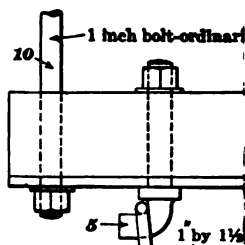
CONCLUSIONS.

1. Limestone does not give free carbon upon decomposition.
2. Limestone may catalytically aid the burning of coal dust when used in very small quantities and at low temperature.
3. The data seem to show that the cooling effect of the limestone dust is so great as to cut down the coal-dust flame and to overcome entirely any accelerating action due to the catalytic action of the liberated lime.
4. The limestone gives a strong sodium flame. This may perhaps increase the luminosity of a flame into which a mixture of limestone and coal dust has been introduced, producing an optical illusion giving the impression that the volume has been increased.



DATA REGARDING PARTS.

Piece No.	Name of piece.	Material.	Number of pieces required.
1	Wooden strip	Wood	3
2	Bottom board	do	2
3	Hinge strap	Steel	2
4	Hanger	do	4
5	Release hook	do	4
6	Blocks	Wood	4
7	Suspension strap	Steel	4
8	Chain	do	8
9	Chain hook	do	4
10	Anchor bolt	do	4
11	Spacing plate	do	2
12	Cross piece	Wood	2
13	Grids	do	2
14	Blocks	do	4



**PART 4.—DETAILS OF CONSTRUCTION OF ROCK-DUST
BARRIERS.^{52a}**

By GEORGE S. RICE.

THE BOX BARRIER.**CONSTRUCTION.**

The box barrier, as is indicated by the name given it, consists of six or more boxes containing incombustible dust, open topped except for a loose waterproof cover, hung loosely from roof supports 2 to 3 yards apart and extending across the entry near the roof in such a manner that the explosion wave will cause them to be upset, thus throwing into the entry a large amount of incombustible dust. The bottom boards of the box are so arranged that after a short fall they are caught by chains attached to the roof, some of the dust being retained on these boards. Two grids within the box, which rest loosely on blocks and are connected to the same chains at distances of 3 and 6 inches below the top of the box, also retain some of the dust and allow the balance to fall through the open spaces. The boxes are hung high enough to be clear of traffic, a requirement that in a thin coal bed may necessitate the roof being "brushed" or ripped down for a distance of 50 or 60 feet.

Plate XXVI shows the arrangement and the details of construction of the preferable type (model C). The boxes, as used at the experimental mine, are about $7\frac{1}{2}$ feet long by 23 inches wide by 10 inches deep, and each box will hold 700 to 800 pounds of rock dust. The length and number of boxes required will vary with the cross section of entryway. In the experimental mine the entries average 9 feet wide and about $6\frac{1}{2}$ feet high. It is recommended that not less than six boxes, or, in a very high entry, seven or eight boxes hung at different heights, be used.

Each box consists of a side frame of inch boards with three longitudinal wooden strips, *1* (Pl. XXVI), on the bottom, one at each side, and one in the middle. Loose bottom boards, *2*, extend over the two spaces between the strips. At each end of the box is a wooden crosspiece *12*, attached to the underside of the frame. Secured to the underside of these wood pieces are steel bars, *3*, with hooks at each end extending beyond the sides of the box. These hooks rest in the eyes of supporting rods, *4*, which also have eyes on the upper ends to engage over the horizontal arm of hooks, *5*, set in the roof or in timbers if the roof is timbered. The horizontal arms of the hooks extend in a direction away from the box and each other. The supporting rods, *4*, diverge slightly in an upward direction and so tend to hold the eyes against the vertical arms of the hooks.

^{52a} - Reprinted from Tech. Paper 84, Bureau of Mines.

the top, so as to reduce to three-fourths of an inch the open space through which the box must swing before striking the rods. Two chains, 8, are attached to a suspension strap, 7, at the edges of each end of the bottom boards. Each pair is attached to an eyebolt or hook, 9, in the roof or overhead timbers.

In the latest form, model C, there are two supplementary grids, 13, connected to these same chains, 3 and 6 inches below the top of the box, by means of heavy wires. Each grid consists of three strips 1 inch by $1\frac{1}{2}$ or 2 inches, with 2-inch spaces between them. The ends of each grid rest on loose blocks while the box is in normal position. The chains from the grids to the roof hooks have 2 to 3 inches slack. This arrangement permits the box to swing without the checking action tight chains would give. The part of the chains from the grids to the bottom boards is so arranged that when the box frame supports release, and the grids fall 2 inches, the bottom boards beneath them also fall to positions 2 and 8 inches below their original positions. The arrangement of the grids prevents the dust falling in a mass, if packed together, but breaks it up and lengthens the time through which dust is falling through the mine entry.

Inasmuch as the dust may become wet if the boxes are placed in a wet part of the mine, or if steam humidifying or sprinkling is practiced, the tops of the boxes should be covered with waterproof coverings hung from roof supports. Planks are placed across the entry at each end of the barrier just below the level of the bottom of the boxes so as either to displace the coal from a car if "topped" to such a height as to be likely to strike the barrier, or to warn persons of their proximity to the barrier.

METHOD OF OPERATION.

If an explosion occurs, the advance air wave causes the box to swing in the direction in which the explosion is advancing until the blocks, 6, strike against the supporting rods on that side and push the eyes from the supporting hooks, causing the frame of the box to swing from the opposite hooks downward, permitting the dust to be discharged in a shower. The pendulum-like arrangement makes the boxes sensitive to the movements of air caused by the lightest explosion. Invariably it has been found that if an explosion has reached the boxes they have operated, and with rare exceptions even the earlier types have extinguished the flame of the explosion.

In a light explosion, when the frame falls the grids and the bottom boards suspended by the chain hangers retain a portion of the rock dust, the larger part of which cascades from shelf to shelf and is gradually spilled into the entry in a continuous shower for eight or more seconds. The projection of this dust by the air current forms



A. VIEW SHOWING EFFECT OF VIOLENT EXPLOSION ON BOX BARRIER.



B. END VIEW OF TYPE A CONCENTRATED BARRIER, AFTER DUMPING.

a thick cloud, extending through the entry for a considerable distance. In an extremely feeble explosion the swinging shelves retain a large amount of rock dust, available for checking a secondary or prolonged flame, which is more likely to occur with a slow explosion than a fast, violent one.

If the explosion is violent, the boxes, including the hanging shelves and bottom boards, are instantly broken to fragments and all of the rock dust is projected in a dense cloud, effectively quenching the flame.

Plate XVI (see p. 454) shows a barrier of six boxes installed in an entry of the experimental mine previous to an explosion test. The details of the supporting arrangements are clearly shown.

Plate XVIII, A (see p. 460), shows a box of model C type on the surface at the experimental mine after it had been dumped. The shelves, with their heavy dust deposits, are at different elevations, and so are in a favorable position for the air currents to blow the dust off and form a thick cloud.

RESULTS OF TESTS.

Plate XVII, A (see p. 455), shows the appearance of a box barrier after a very light explosion. It can be seen from the appearance of the boxes on the floor that there was just sufficient pressure to drop the boxes to the floor and they were damaged very little. A large amount of the dust was retained on the shelves, and would have been available to check a secondary explosion had one occurred.

Plate XVII, B (see p. 455), shows the appearance of the barrier after a somewhat stronger explosion. The boxes are more broken up and some of the shelves are broken. Little dust remains on the shelves.

Plate XXVII, A, shows the appearance of a box barrier after an explosion more violent than that after which Plate XVII, B, was taken. Fragments of the boxes were thrown a considerable distance out by the position of the barrier. The shelves were broken and only fragments remain suspended. The dust on the floor is seen to be evenly distributed. In this barrier the boxes were hung by having the hooks of the supporting rods inserted in stirrups set in the roof, some of which can be seen in the illustration. The later method, by which eyes are used with hooks in the roof, is preferred to this arrangement of hooks inserted in stirrups.

THE CONCENTRATED BARRIER.

The concentrated barrier, as its name implies, consists principally of two large but shallow containers of incombustible dust placed overhead across the entry way and supported near the roof by hinges and catches. The latter in turn are held by a leverage system

advancing air wave, operating against swinging vanes, reaches a predetermined amount. The vanes are hinged planks 100 feet or more from the barrier on either side, the pressure being converted into a pull by a chain passing around a pulley and transmitted by a strong wire from the chain to the releasing mechanism.

When the catches are released the hinged containers swing quickly downward under the heavy load of rock dust.

TYPE A CONCENTRATED BARRIER.

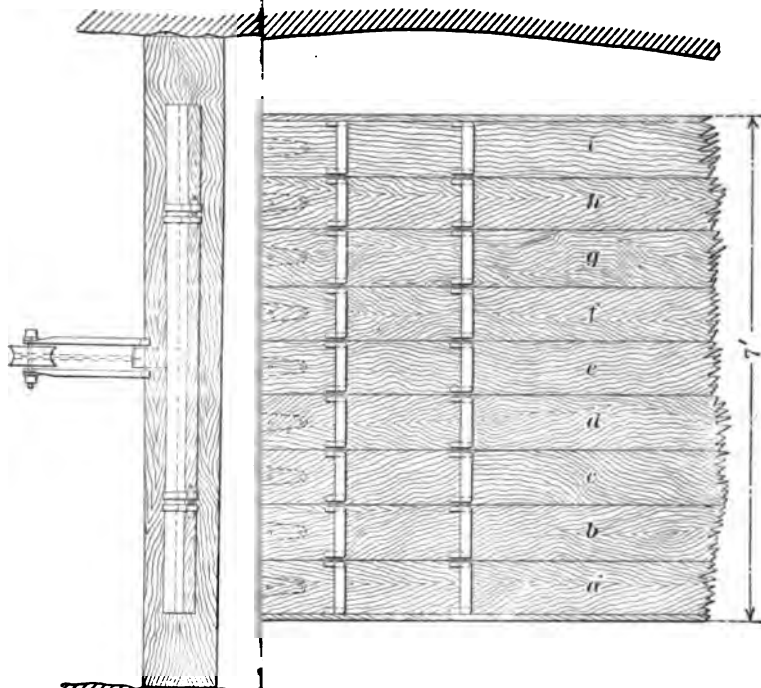
Two different forms of containers have been designed and tested, with successful results. In one form, called the A type, the bottom boards and cross boards, or shelves, of each compartment are nailed fast to its sides and ends. The container is hinged at one end, the other end being free, when its catch is released, to swing to the ground. The box, if not wrecked by a violent explosion which would release automatically all its dust, would then remain at an angle of about 45° , blocking the passageway and retaining about one-third of the dust load on its cross shelves. The duplicate container will have similarly swung down in the opposite direction, forming with the first container an inverted V-shaped obstacle across the entry way.

This arrangement is particularly favorable in the case of a very light explosion, as the entry will be practically blocked from either direction, and with dust on cross shelving in readiness to extinguish a delayed or secondary flame.

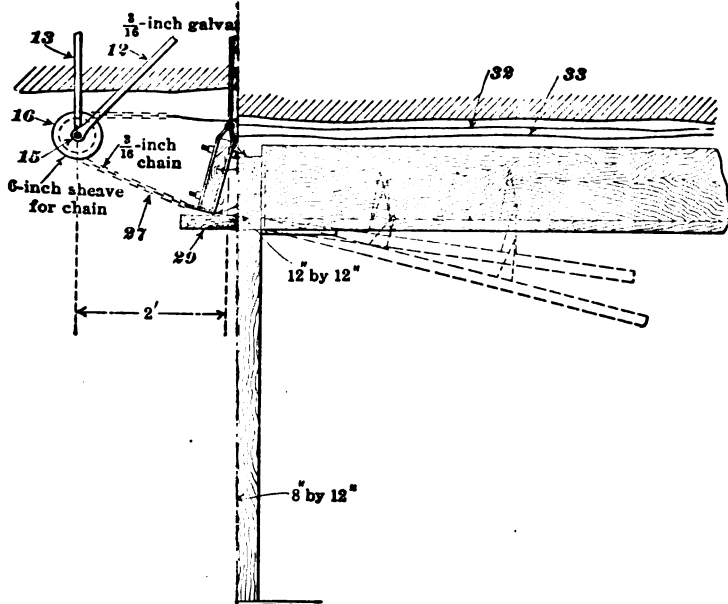
Plate XXVII, *B*, is an end view and Plate XX (see p. 472) is a side view of a type A barrier that has operated. The boxes were slightly damaged, yet a large amount of dust was retained on the cross boards. The disadvantage of this type of container is that if operated when a person happened to be passing under it, he might be seriously injured. Its use should, therefore, be confined to those entries not regularly traversed by employees, except examiners and officials, such as airways, and connections between panels or different divisions of a mine. In many disasters, if the explosion could have been stopped in a connecting entry or passage, many lives would have been saved. At the top of Plate XXVII, *B*, is shown an auxiliary swinging vane (see also *11*, Pl. XXVIII); wires from the advance vane pass overhead (see Pl. XXVIII).

TYPE B CONCENTRATED BARRIER.

In the second or B type of concentrated barrier the bottom boards are not fastened to the sides and ends and the frame does not fall with the bottom boards, but remains attached to the main timber



d, *f*, and *h* can drop 9 inches.



framework. Each bottom board is separately hinged to a central timber, the other or free end of each resting on a hinged angle iron. When the catches are released the angle iron drops, releasing the boards; these swing down to various distances until caught by tether chains attached to the roof or overhead timber. A thick shower of incombustible dust is thus discharged into the path of the explosion which has operated the barrier, the shower continuing for some seconds if the explosion is delayed or is very light, but if the explosion is violent and consequently fast moving the barrier will be broken to pieces and then all the dust will be launched into the air and scattered over a great length of entry.

The type B concentrated barrier is more generally applicable than the type A barrier, as in case of accidental tripping a person caught underneath would be struck by a single plank hinged at one end, and free end falling at most only 18 inches. It is true this might give a severe blow, but it should not cause a serious injury. Also, the chances of such an accident would be so remote they would seem to be negligible.

There is no difficulty in arranging this barrier over an electric trolley road. The type A barrier is especially suited to place in connecting passages of adjacent mines or extensive panels.

DETAILS OF CONSTRUCTION OF TYPE B CONCENTRATED BARRIER.

The outward appearance of either type of barrier is the same and they have similar operating mechanisms.

Either type of concentrated barrier, as indicated above, has two platforms or containers of dust and two sets of levers and vanes that are set up symmetrically with reference to the middle point of the barrier. Plate XVIII *B* (see p. 570), shows the barrier in position in a mine entry. In Plate XXVIII the lower view shows an elevation through the center line of the barrier, showing a complete set on one side of the middle support of the barrier and a part of the compartment on the other side; the upper view shows a plan of the same part of the barrier. Plate XXIX shows certain of the parts in detail. Data regarding the parts shown in the two plates are given in the table following:

55617°—22—38

Data regarding parts of type B concentrated barrier.

Piece number on Plates XXVIII and XXIX.	Name of piece.	Material.	Number of pieces required.
1	Hanger.....	Steel.....	12
2	Fulcrum pin.....	do.....	2
3	do.....	do.....	2
4	Angle or guide block.....	Steel or wood.....	4
5	Fulcrum bracket.....	Steel.....	4
6	Release bar.....	Steel and brass.....	2
7	Tripping lever.....	Steel.....	2
8	Bracket.....	do.....	4
9	Pivot or hinge connection.....	do.....	4
10	Connecting strap.....	do.....	4
11	Vane (wood).....	Wood and steel.....	2
11a	Vane strap.....	Steel.....	16
12	Hanger brace.....	do.....	4
13	Sheave hanger.....	do.....	4
14	Vane hanger.....	do.....	5
15	Sheave pin.....	do.....	2
16	Sheave.....	Cast iron.....	2
17	Support arm.....	Steel and wood.....	2
18	Vane.....	do.....	2
18a	Vane plate.....	Steel.....	2
19	Angle iron.....	do.....	2
19a	Hinge connection.....	do.....	2
20	Dust check ^a	Galvanized iron.....	54
21	Side frame.....	Wood.....	6
22	Hinge.....	Steel.....	18
23	Collar.....	Wood.....	1
24	Cross timber or collar.....	do.....	2
25	Bumping block.....	do.....	2
26	Support wire.....	Steel.....	2
27	Chain.....	do.....	2
28	Collar.....	Wood.....	2
29	Guards.....	do.....	4
30	Bottom plank.....	do.....	18
31	Chain ^a	Steel.....	18
32	Galvanized wire.....	do.....	2
33	Chain.....	do.....	2
34	Chain pulley.....	do.....	4

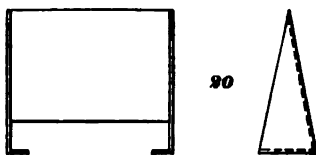
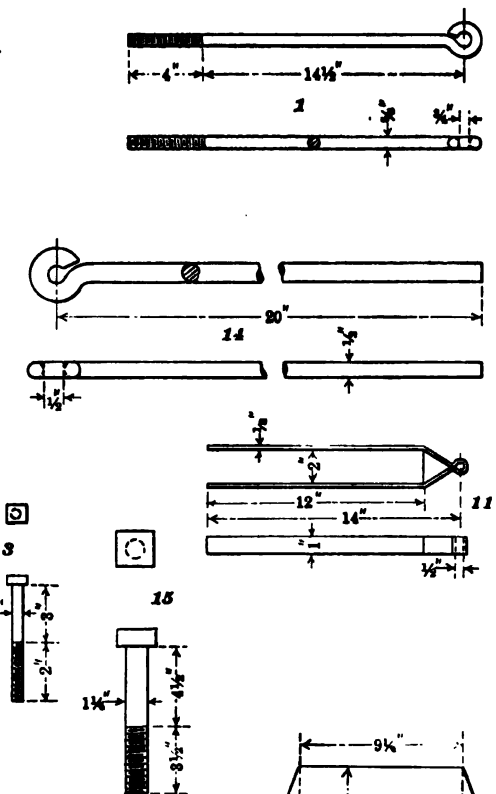
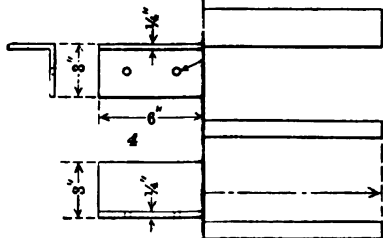
^a For use in type B only, other parts common to both barriers.

The dust compartments each measure 7 by 7 feet by 12 inches deep and together will hold about $3\frac{1}{2}$ tons of limestone dust. The bottom of each compartment consists of a number of unconnected and separately hinged planks *a* to *i* (Pl. XXVIII), with a side frame, *21*, of 2-inch plank touching the bottom planks, but spiked to the main frame so as not to fall when the bottom boards are released. Each of the bottom planks is attached by a hinge, *22*, to the middle cross timber or collar, *23*, which separates the two dust compartments. The free ends of the planks of each compartment are held up, when the planks are in the normal horizontal position, by an angle iron, *19* (Pls. XXVIII and XXIX), bolted to four steel arms, *19a* (Pl. XXIX), which are pivotally supported by bolts through cross timber, *24* (Pl. XXVIII).

DETAILS OF CONSTRUCTION COMMON TO TYPE A AND TYPE B.

METHOD OF OPERATION.

The angle iron is maintained in a position supporting the planks through a system of levers, *17*, *6*, *7*, which are pivotally supported



from cross timbers or collars. Levers 17 and 6 reduce the load thrown on the tripping lever 7 so that it can be easily shifted by the wires from the vanes, causing the barrier to dump. The short arm of lever 17 engages under the angle iron, and the long arm rests beneath the short arm of lever 6. There are two angle brackets preferably of brass or other noncorrosive metal on the sides of this lever near the end of the long arm, the under surfaces of the horizontal flange of which are curved upward. Lever 7, called the trip lever, is two-pronged at the lower end and the ends of the prongs are turned in horizontally toward each other. The horizontal surfaces engage under the curved surfaces of the brackets and serve to hold the lever in a horizontal position until the trip lever is pulled one way or the other. The contact between lever 7 and lever 6 is shown in Plate XXVIII.

A small movement of lever 7 in either direction causes it to disengage from lever 6, which withdraws the support from lever 17 and the angle iron, resulting in the dropping of the free ends of the dust compartments. In the type B barrier, the bottom planks are not permitted to swing to the floor, but are caught by stay chains attached to hooks in the roof or cross timbers. As arranged in recent tests at the experimental mine alternate planks drop 18 inches, the intermediate planks having a drop of only 9 inches. The arrangement of adjacent planks at different elevations allows a considerable quantity (about one-fourth) of the rock dust to fall from the planks and to continue to sift between them for several seconds, the remainder of the dust being held on the planks to be brought into action by the waves immediately preceding the flame or actual explosion. The reason for using the chains is twofold. First, to prevent serious injury to an employee in case of accidental tripping. Second, the checking of the planks in the positions shown by the dotted lines in the lower view in Plate XXVIII tends to prolong the period in which the dust is sifting into the air current, and also causes a considerable amount of dust to be retained on the planks. It frequently happens that the first advance air wave will trip off the barrier mechanism by means of the vanes some time before the flame of the explosion reaches the barrier; in such an event, the prolonged showering of the dust together with that retained on the planks will provide the necessary amount of rock dust to extinguish the flame when it arrives. A violent explosion will demolish the barrier framework and launch all the dust. The flame of a violent explosion quickly follows the advance air wave so the rock dust will be where it will be most effective—that is, in the air.

Three cleats or dust checks (20, Pl. XXVIII), nailed to each plank, assist in retaining dust on the planks when the planks fall from their original position. The bottom of each dust check has a small open-

ing that permits a gradual flow of dust from it and thus increases the length of time during which dust is falling from the inclined planks.

The operation of the trip lever 7 can be caused by any one of the advance vanes 11 or 18, hung at various selected distances in advance of the barrier. Vane 11 has attached to it a bumping block 25, the other end of which is supported by a wire 26 to the roof. When an explosion waves moves this vane toward the barrier, the bumping block pushes the lower end of lever 7, causing it to disengage from lever 6.

In some rapidly moving explosions this operation might not be quick enough so that the barrier would fall in time to quench the flame; to provide for such explosions, vane 18 is hung about 100 feet in advance of the barrier, one on either side. Attached to the underside of vane 18 is a chain 27 which passes around a sheave 16 and is then attached to a wire that is secured to the top of the trip lever 7. When vane 18 is swung toward the barrier the motion is reversed by the pulley arrangement and the top of lever 7 is pulled away from the barrier, causing its disengagement from lever 6. To provide for instances when vane 18 might be out of order, or if an explosion developed between it and the barrier, similar advance vanes connected by chain to the same wire may be placed at intermediate points.

A wire or chain from the top of lever 7 passes over the dust compartments and is fastened to a chain which, passing around two small pulleys attached to beam 28, is connected to the lower part of lever 7 of the opposite compartment and, when pulled, causes that lever to disengage from lever 6 on that side. Both levers would thus be operated by the same means. At points beyond lever 7 on the far side of the barrier are vanes similar to vanes 11 and 18 and connected in a similar manner to the trip lever on that side of the barrier, thus enabling the barrier to be operated by an explosion coming from either direction.

A plank is placed across the entry beneath each vane to serve as a guard to prevent the barrier from operating through being struck or pushed accidentally.

RESULTS OF TESTS.

Plate XXI (see p. 473) shows the appearance of the barrier after a light explosion. The planks have all been caught by the chains and have retained much of the dust. The depth and the position of the dust beneath the barrier are clearly indicated. In this explosion a match fastened to a peg in the roof 15 feet beyond the barrier was not ignited, indicating a quick quenching of flame. The photograph was taken looking in by toward the origin of the explosion.

The appearance of the barrier after a more violent explosion test can be seen in Plate XXIIA (see p. 474). In the foreground is the bumping vane with the bumping block hung from it. In the background can be seen the cross timbers and the planks, which were thrown 15 to 30 feet from their original positions. The even distribution of dust on the floor can be noted in the foreground, the black patches being footprints of persons who have walked through the entry between the time of the explosion and the time the photograph was taken. This photograph was taken looking outby in the direction the explosion went.

DETAILS OF TIMBER AND FRAME WORK.

Five crossbars or collars are necessary in the construction of the barrier. These can be set in grooves in the rib or on posts as in an ordinary timber set. The collar 23 (Pl. XXVIII, see p. 570), as used at the experimental mine, is a 10 by 12 inch timber, whereas collars 24 and 28 are each 8 by 12 inches. The two timbers 24 (only one of which is shown in Pl. XXVIII) and timber 23 are placed at an equal elevation at a height at least sufficiently great to avoid being struck by loaded cars. The two timbers 23 (only one of which is shown in Pl. XXVIII) are placed 2 inches above the elevation of timbers 24 and 28, to allow the lever 17 to swing through an angle great enough to permit the unobstructed fall of the plank of the dust compartment.

The device as constructed at the experimental mine and tested in the experimental explosions contained approximately $3\frac{1}{2}$ tons of limestone dust. The entry at the point at which the device was placed has a cross section of 63 square feet; the dust load, therefore, was equivalent to about 110 pounds per square foot of section. If the cross section of the entry in which the device is to be used varies materially from that given, the proportions of the dust compartment should be changed to give the same ratio of loading to a square foot of section, so as to insure effective operation in the event of an explosion.

ROCK-DUST-PROTECTED MINE-AIR STOPPING.

Whenever there has been an explosion of any extent almost invariably the stoppings have been thrown down. In fact, it is impossible to build at moderate cost a masonry or concrete stopping that will withstand an explosion pressure of over 100 pounds per square inch as the stopping must be reinforced with iron. The reason is evident, for as the exposed surface is large the total pressure is great. For example, with a pressure of 100 pounds per square inch and a stopping having a superficial area of 50 square feet, a total pressure of 360 tons would be applied with a hammer-like blow.

passage of flame to parallel entries in many explosions, which otherwise might have been confined to a small area, the design of some form of rock-dust barrier, in connection with stoppings at certain points, seemed desirable. The device as designed can be used in connection with any form of mine stopping or may be substituted for the usual masonry or wood stopping.

CONSTRUCTION.

The device consists of a series of shelves one above another, set up on either side of any kind of a stopping, and loaded with rock dust, or, if there was no stopping at the place where the device is set up, rock dust may be piled between the two sets of shelves. When a strong explosion strikes such a stopping, either the stopping as a whole goes out, discharging the rock dust in a cloud, or the stopping proper, the solid part, is blown out, upsetting the shelves on the far side. In a light explosion it is expected that if the shelf posts on the near side of the stopping are firmly set, they may remain in place even though the solid part of the stopping blows down, and then the explosive blast would blow the dust from the shelves, producing a thick dust cloud which would quench the flame. It is particularly difficult to check or stop a light explosion in which the flame is delayed, yet the danger to life from a light explosion is as great as from a strong one. The arrangement of rock-dust shelves is designed to extinguish the flame of either a light or a strong explosion which may pass into the crosscut or cut-through.

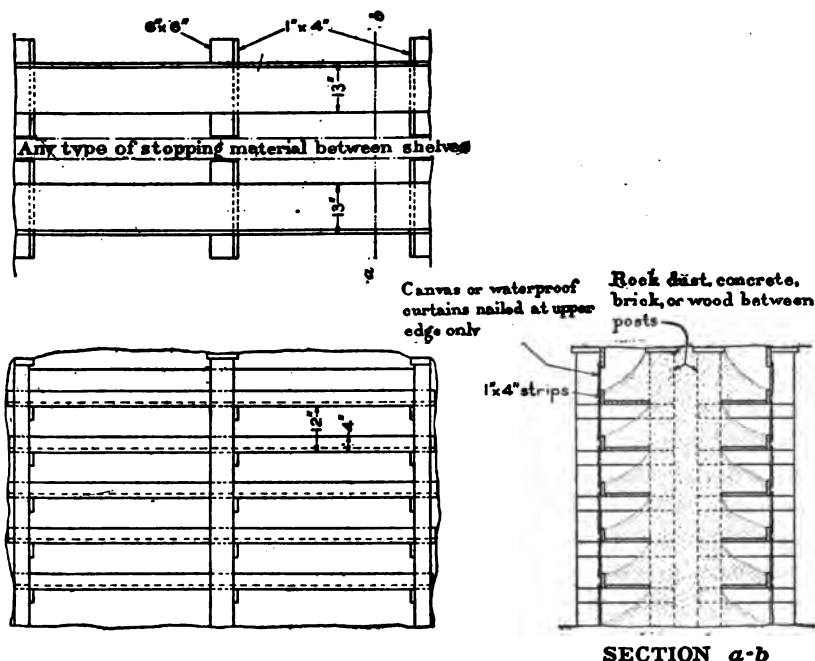
Figure 80 shows a plan of the shelves on both sides of a stopping, a front elevation, and a vertical transverse section showing the sets of shelves with the space between filled merely with rock dust instead of brick, concrete, or wood, or some other stopping material.

METHOD OF ERECTION.

Six posts in two rows of three each are firmly wedged in place on either side of the stopping, the two rows being 12 inches apart. Cleats are nailed to each pair of posts at vertical intervals of 1 foot, and on these are placed boards 12 inches wide to act as shelves. Four-inch strips are placed inside of the posts along the front of the shelves to assist in holding the rock dust in place. When the shelves have been loaded with as much rock dust as the angle of repose of the dust will permit, short curtains are hung from the top of the shelves to just beneath the upper edge of the front strips to protect the dust from becoming wet. The object of not using a large single curtain is twofold—first, the use of separate curtains makes it easier to inspect all parts of the stopping; second, a single curtain would act like a sail and cause the barrier to go out as a whole, whereas in an

into the shelf compartments, and do not prevent the continued blowing of the dust from the shelves in the event of a delayed explosion.

Although a set of such shelves can be placed on either side of any kind of a stopping, it was thought that in a dry mine a double set with a 6 to 12 inch space between shelves could be filled with rock dust and made an effective stopping without any containing walls. Such a stopping would offer little resistance to the passage of the explosion, and the blowing of the dust off the shelves would effectively quench any flame that might attempt to pass through. This



SECTION a-b

FIGURE 80.—P. an, elevation, and vertical cross-section of rock-dust-protected mine-air stopping.

form of stopping has proved successful in extinguishing flames in each of several trials.

Plate XXII, *B* (see p. 474), shows a set of shelves installed in a mine before the curtains had been hung. Plate XXIV, *A* (see p. 480), shows the same set after the curtains had been hung.

Plate XXIV, *B*, shows the appearance of a rock-dust stopping after an explosion. A 1-foot space between the two sets of shelves was filled with limestone dust. This dust compartment, as anticipated, acted like a solid wall, and the explosion threw down the set of shelves on the side away from the explosion or the side from which the picture was taken. The set shown was on the near side. The explosion, passing through the spaces between the shelves, blew most

of the dust off the shelves. The flame did not pass beyond the stopping, as was demonstrated by nonignition of pure coal dust beyond.

Plate XXIII, A (see p. 475), shows the appearance of the remains of a rock-dust stopping after a stronger explosion. The pile of dust in the foreground had been piled at the foot of the nearest set of shelves. All the framework except one post has been blown away by the explosion. Except for a small pile in the foreground, the dust appears to have been uniformly scattered along the entry. The flame was effectively quenched by the device.

ROCK-DUST-PROTECTED VENTILATING DOOR

CONSTRUCTION.

Inasmuch as ventilating doors are usually placed at the entrance to butt and side entries, points at which it is particularly important to have some means to insure limiting the explosion area, it was thought that advantage could be taken of the well-known vulnerability to wreckage of such doors to design a device for producing a thick cloud of rock dust to check any explosion that might start in spite of other protection.

The rock-dust-protected ventilating door consists of a mine door of the usual type, though as small as is expedient without interference with haulage; around the frame of the door, at the sides and overhead, are constructed compartments to be filled with incombustible dust. The compartments are constructed without the use of spikes or bolts in such a manner that the walls and overhead compartment floor are held in position by the door frame. The frame is strongly constructed, and its displacement as a whole by an explosion causes the collapse of the compartments and the consequent projection of the rock-dust contents into the entry. The floor boards of the upper compartments are hung by chains secured to the roof or, in case of poor roof, to roof timbers. The chains allow the boards only a limited fall to different heights, so that the boards delay the fall of some of the dust and also retain some of the load, which is then available to quench a delayed flame or a secondary explosion. This arrangement is primarily intended for a light explosion, which is the most difficult kind to check; as the pressures are low it is necessary to have a device that will be sensitive to a blast of air. An explosion having a strong pressure offers little difficulty, as then the whole framework and the compartments are demolished and the mass of rock dust is launched into the air, quenching the explosion.

Figure 81 shows a plan view of the device, indicating the relation of the side compartments to the doorframe, a front elevation of the device, and a vertical section along the line *a-b*.

As already mentioned, the mine door is made as small as practicable for the mine conditions, so as not to inconvenience haulage operations, and the remaining entry space is utilized for dust compartments. If the roof is low it may be necessary to take down some of it. The excavation should be tapered off gradually in either direction.

METHOD OF ERECTION.

Crossbars, 5 (fig. 81), are set near the roof upon posts in grooves in the rib. Beneath them posts, 6, are set up and firmly wedged or nailed to bars 5. The side planks, 8, of the side dust compartments are then temporarily nailed during construction to the outside of the posts. The doorframe is set up between the planks of the two side compartments, the crossbar, 3, being of sufficient length to force or spring in the planks a little, so that they will be held firmly in position when the rock dust presses against them. After the frame is in place the temporary nails in the planks, 8, are withdrawn. Braces, 14, are placed against the side of the frame on the opposite side to that on which the door will be hung, so that the frame will be enabled to withstand the shocks from the door closing violently with the ordinary mine operations without dislodging the frame. The door is hung by the usual type of hinges, 2, to the doorframe in such a way as to be self-closing. The short planks, 7, are set in place on the inside of the posts at the ends of the side compartments; these also are not nailed but are held in position by the dust loading.

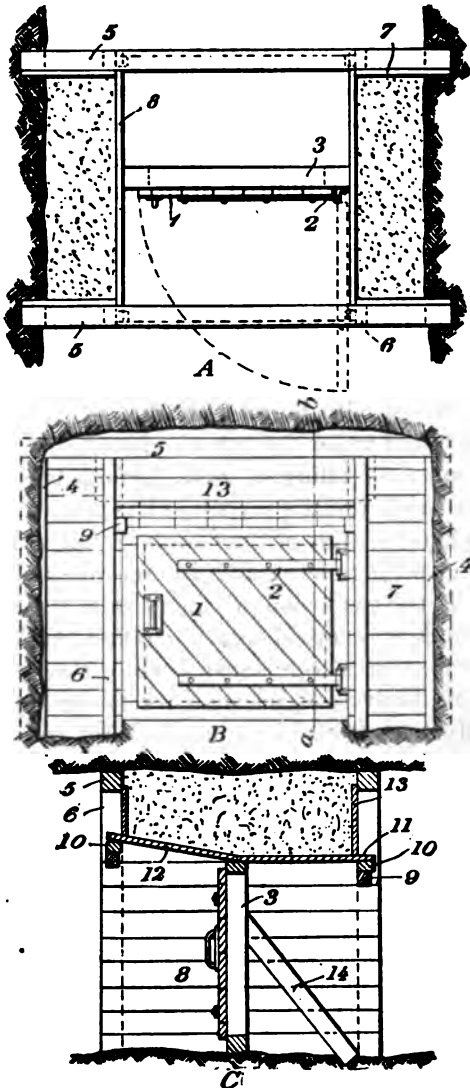


FIGURE 81.—Rock-dust-protected ventilating door. *A*, plan; *B*, front elevation; *C*, vertical section through *a-b*.

Crossbars, 10, are then placed on cleats, 9, attached to the posts, 6. The crossbar on the door side of the frame is preferably placed somewhat higher than the other crossbar, 10, as the free end of a self-closing door needs additional height when open. Short planks, 12, are placed from the crossbar, 3, of the doorframe to the crossbars, 10. End planks, 13, are placed from rib to rib to inclose the ends of the upper compartments.

In testing this arrangement in explosions, as with the concentrated barrier and box barrier, it was found desirable to fasten the floor planks of the upper dust compartment by chains to the roof, allowing them only a limited drop, adjacent boards dropping different distances. The reason for this is, as previously mentioned, that under some circumstances the preliminary air wave may be some distance ahead of the flame, and if the advance air wave or if the shock wave of a violent stage of the explosion farther in the interior of the mine arrives before the flame, which may be delayed, there will be rock dust still remaining on the shelves to quench the flame.

It was also found that the ends of the planks, 8, tended to bulge outward when the side compartments were filled with dust. To prevent the spilling of dust through the crack, a 2 by 4 inch scantling was nailed near the ends of the planks, 8, to fit just inside of planks, 7. When the ends of the planks, 8, bulge outward, the scantling prevents the spilling of the dust by making a sliding joint.

If the explosion advances from the side on which the door is hung, the door is forced tightly against the frame and even a light pressure over such a large surface will quickly dislodge the frame unless it is well braced to prevent its being too sensitive. If the explosion advances from the opposite side, the door will be apt to blow open, and so not receive the full force of the explosion wave; but if the frame is not braced in that direction, it is dislodged about as easily as from the other direction. It has been found in the tests already made that the frame is dislodged without delay, irrespective of from which side the explosion comes. However, it is desirable to make the doorframe proper relatively deep and wide to present considerable surface to an explosion to make sure that it will be blown out and thus release the rock-dust compartments as described.

Plate XXIII, B (see p. 475), shows a rock-dust-protected ventilating door with the end board of the upper compartment removed to show the chains attached to the bottom boards of the compartments.

RESULTS OF EXPLOSION TESTS.

Plate XXX, A, shows the effects of an explosion on a rock-dust-protected ventilating door in a mine entry. The doorframe was blown out entirely and the plank of the side compartments scattered out into the entry. The explosion was sufficiently strong to break



A. EFFECTS OF EXPLOSION ON ROCK-DUST-PROTECTED VENTILATING DOOR.



B. RESULTS OF A VIOLENT EXPLOSION ON ROCK-DUST-PROTECTED DOOR.

some of the chains and pull down some of the roof in which chain hooks were fastened. The wide distribution of the dust is plainly shown. The device successfully stopped the explosion.

Plate XXX, B, also shows the results of a violent explosion on a rock-dust-protected ventilating door. The entire framework of the barrier has been blown away, the only pieces remaining being a few chains hanging from the roof. The dust is scattered uniformly along the entry as far as one can see. In this explosion the flame was effectively quenched by the rock-dust shower.

ROCK-DUST-PROTECTED OVERCAST.

CONSTRUCTION.

In mine explosions, overcasts are almost always disrupted or demolished owing to the large extent of surface on which the explosive force can act. For example, if the pressure of the explosion is only 20 pounds per square inch, a relatively light pressure, the total lifting pressure on the floor of an ordinary 9 by 12 foot overcast would be 130 tons and about 100 tons pressure on either side. As a result of their destruction the explosion frequently passes to other parts of the mine. It was thought, therefore, that advantage could be taken of the vulnerability of the overcasts to produce a dense cloud of rock dust to extinguish an explosion at such points. The rock-dust-protected overcast is designed to give such an effect.

The device consists of an overcast of any type of construction, the floor and sides of which are protected by rock-dust compartments. Figure 82 represents a longitudinal section of an overcast showing the arrangement of dust compartments, a transverse section, and a plan view indicating the arrangement of the device in the mine, as well as certain details of construction are also shown.

METHOD OF ERECTION.

In A, figure 82, 1 indicates a main entry and 2 an airway, which are separated by the overcast. The side walls are made double with a space between them, 2 to 3 feet wide, which is filled with rock dust, the outer sides may be planned like the rock-dust stopping, described above. The walls may be made in any suitable manner, the framing in the diagram showing one method of construction. The framing is preferably made light so that an explosion will readily disrupt the walls and permit the rock dust to be projected into the entries. In like manner the floor of the overcast has a compartment, 4, built above it with angular dust compartments, 9, connecting it with the side compartments. All of the hollow space is filled with rock dust. If the overcast is built in a place where water is dripping from the roof, it is desirable to place some waterproof covering over the top of the dust compartments in order that the

dust will not become wet. No piles of "slate" or gob should be permitted to be placed against the side walls of the side compartments, as such piles tend to prevent the most efficient operation of the barrier in the event of an explosion.

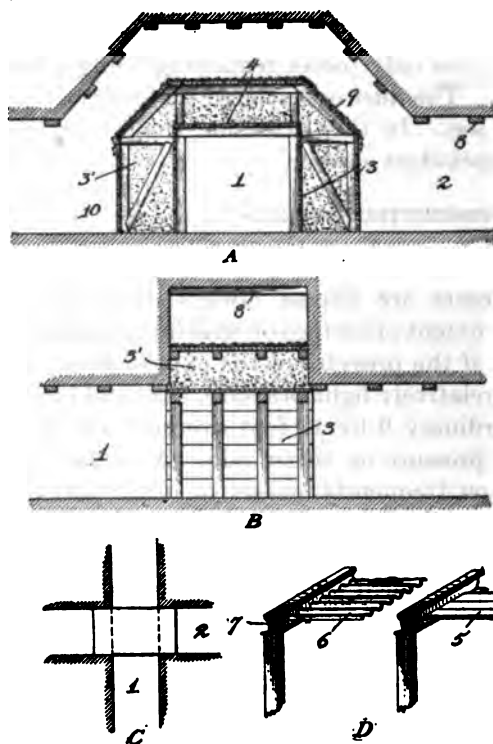


FIGURE 82.—Rock-dust-protected overcast. A, longitudinal section; B, transverse section; C, plan view; D, details.

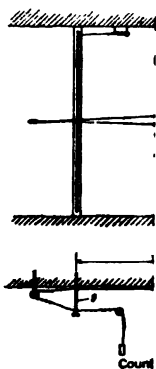
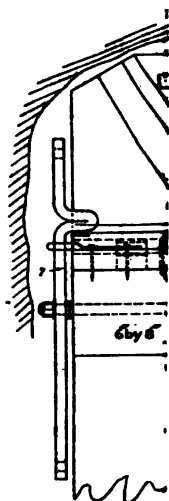
overcast in an experimental explosion, but in view of the success attending the tests of the other kinds of rock-dust barriers it is thought by the engineers of the bureau that the device will operate successfully.

TROUGH ROCK-DUST BARRIER.

The "trough barrier" was the latest designed by the senior author of this bulletin as an alternative to the hanging-box type of barrier, or of the concentrated barrier; it embodies from the latter the employment of the advance tripping vanes.

This barrier was tested at the experimental mine and successfully prevented the passage both of strong explosions of coal dust and of feeble ones, and also of an explosion of dust in air which contained a small percentage of inflammable gas.

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DESCRIPTION OF BARRIER.

The essential features of the barrier (Pl. XXXI) are six fixed troughs placed about 6 feet apart, across the entry and close to the roof, each of which contains longitudinal bars, 1, 2, and 3, or grids, which separate the mass of rock dust filling the trough and, in case of the barrier being dumped, break up the mass of dust and cause it to cascade in falling; a drop shelf, 4, which is held up by chains after falling about 6 inches; hinged bottom boards, 5, each of which is held up along one edge by a wood strip, 12, which acts as a hinge, and by supporting levers, 6, and trip levers, 7, operated by strong wires, 8, from advance vanes, 9 and 10. Each trough is supported on the four corners by roller bearings, 11, which rest on side frames, or on studs between posts if the passageway or entry is timbered. Also, if the entry is timbered, each trough may be set in a space between collars. In falling, the bottom boards, after clearing the strip hinges, 12, are caught by loose chains as a safety precaution should the barrier be dumped when some one was passing under it. The troughs extend across the full width of the entry and if it is 3 feet wide the six troughs will hold 2 to 2½ tons of rock dust. On each side of the set of troughs are two advance vanes, 50 and 100 feet from the barrier, which are similar to those employed for the concentrated barrier described in pages 572 to 574. Two tripping wires, one on each side of the entry, are joined at the outer or advance vane to a chain which passes around a pulley and back to the lower edge of the vane; the intermediate vane requires two chains and pulleys, one for each wire. Hooks or staples in the roof, or collars if the entry is timbered, keep the wires from sagging and overhead out of the way. Each wire trips the levers on its side of the entry. The wires from the set of advance vanes "ahead" of the barrier connect to the upper ends of the tripping levers, 7, and those from the advance vanes "behind" the barrier connect to the lower ends of the tripping levers. By means of this arrangement, if a comparatively light explosion pressure reaches the vanes which are ahead, with reference to a point in the entry, the weight of the vanes behind the barrier will not have to be overcome by the wires in pulling the tripping levers, as indicated in Plate XXXI, A and B. The terms "ahead" and "behind" are merely explanatory, as the barrier is symmetrical and an explosion approaching from either direction will operate it.

The weight carried on each supporting lever is about 150 pounds, and as the leverage is in the ratio of 2 to 1, the upward pressure on the tripping lever is 75 pounds. The sliding frictional resistance of the catch, by interposing a sheet of brass, will not exceed 15 pounds; and if 1 pound be allowed for the turning friction of the lever, the force required to trip it is about 16 pounds. The tripping wires are

fastened to the tripping lever at points twice the distance from the axis 13 that the catches are, hence the pull required to trip the lever is about 8 pounds. For 6 levers the pull on one wire is about 48 pounds, and for 12 levers, 6 on each wire, it is about 96 pounds. An advance vane has about 8 square feet of exposed surface, and as one edge is hinged, the pressure required to operate the barrier is about 24 pounds per square foot of vane surface. Such a pressure would be given by an air current having a velocity of 70 miles per hour, or about 102 feet per second, as calculated from the Smeaton formula, $P = 0.005 V^2$, or if one uses the Martin formula, $P = 0.004 V^2$, by a current with a velocity of 113 feet per second. In either case the velocity is less ²² than was observed in the lightest explosion in the tests in the experimental mine, and yet far greater than that of any ventilating current. Moreover, the total force of the pull (96 pounds) required would be too great for the barrier to be accidentally tripped by men or boys in passing. The vane is also protected by a plank placed across the entry underneath the vane, but with sufficient clearance for cars and men.

In the event that the vanes should fail, the arrangement of resting the corners of each trough on ball bearings or rollers (which should be made of bronze to prevent corrosion) permits the trough to be pushed laterally by the force of an explosion, causing the bottom rests to slide off the side levers and permitting the bottom to fall and discharge the dust as readily as if the trigger levers had operated. However, to move a trough in this way requires a greater wind pressure than is necessary with a vane; hence for sensitive action the chief reliance is placed on the vanes. In the case of a violent explosion the sensitiveness of the barrier is not a matter of much importance, as then the barrier troughs are completely smashed by the advance wave, and the two tons of rock dust are instantly whirled away in a cloud, cooling and quenching the flame.

A mixture of rock dust and coal dust that contains 75 per cent of rock dust will prevent the propagation of an explosion if $3\frac{1}{2}$ pounds of rock dust per linear foot of entry is present. This quantity of rock dust, if all of it is raised into the air, is equivalent to 1 ounce per cubic foot of space. As there is over 4,000 pounds of rock dust in the barrier, if but 30 per cent, or 1,200 pounds, was raised in the air by the advance wave, it would fill the space, at the above rate of 1 ounce per cubic foot, of an average entry (60 square feet in cross section) for a linear distance of 320 feet. The flame of an explosion, after it is well started, judging from the photographic records so far obtained from the experimental mine manometers, has a longitudinal length, from fore front of flame to back, of 20 to rarely exceeding

²² Exceptions to the minimum velocity cited have been noted when an explosion is dying away when there is a backward swing of the column of gas or air.

100 feet; hence it is believed that the quantity of rock dust provided in the barrier gives a good margin of safety, provided the rock dust is launched into the air sufficiently in advance of the flame, and this condition, it is believed, is well provided for by the advance vanes.

COMPARISON WITH OTHER BARRIERS.

In comparison with the box barrier and the concentrated barrier the trough barrier has the merit that it is more cheaply constructed than the concentrated barrier, though not so compact, and it is thought that it is equally sensitive and efficient, but possibly not so positive in separating divisions of a mine as the concentrated barrier of the solid platform type. The trough barrier does not take so much headroom as the box barrier; it is more sensitive for light explosions, and is better adapted for trolley roads, though it necessitates greater distance for installment on account of the advance vanes. It requires only 14 inches space above necessary headroom, and if an entry is timbered each trough may be placed between timber sets.

CONCLUDING REMARKS.

In conclusion, it may be advisable to state again and further to emphasize that, although the stopping devices have been described in detail so they may be easily constructed by mine mechanics, it is not the thought of the designer nor of the joint authors of this publication that these devices will in any way take the place of systematic treatment of the coal dust. Prevention of ignition of either fire damp or coal dust by methods described in previous pages is safer and more certain than attempting to stop an explosion once started.

PART 5.—THEORETICAL MAXIMUM PRESSURES OBTAINABLE BY THE EXPLOSION OF MIXTURES OF COAL DUST WITH AIR, AND METHANE WITH AIR.

By W. L. EGY and H. P. GREENWALD.

The question has frequently been raised as to the temperature and pressure attainable in coal-dust or gas explosions. This question can be made the subject of theoretical calculations after some fundamental conditions are assumed. These fundamental assumptions are:

1. The temperature at which combustion starts.
2. The composition of the coal.
3. The composition and original pressure of the air.

Other factors used are:

4. The heat produced by the combustion.
5. The specific heat of the products of combustion.

1. The temperature at the start of combustion is taken at 20° C. (68° F.). The combustion is supposed to take place in a constant volume, this being the closest approximation of what happens in a

mine explosion, and it is assumed that no heat will be lost to surrounding volumes.

2. The coal taken for the purpose of this calculation is laboratory sample number 12,562; it was collected in the summer of 1911 from the east side of the air course at A 490. Its ultimate analyses showed the following composition on the basis of 1 gram of coal:

<i>Analysis of laboratory sample of coal on the basis of 1 gram.</i>	
	Gram.
Hydrogen (H ₂).....	0.0529
Oxygen (O ₂).....	.0918
Carbon (C).....	.7578
Nitrogen (N ₂).....	.0153
Sulphur (S).....	.0153
Ash.....	.0669
Total.....	1.0000

In the combustion of methane, no assumption is necessary, methane being a definite chemical compound.

3. Moisture-free air is assumed, and its composition by weight is taken as follows:

<i>Analysis of air on the basis of weight.</i>	
	Per cent.
Nitrogen (N ₂).....	75.51
Oxygen (O ₂).....	23.15
Argon (A).....	1.29
Carbon dioxide (CO ₂).....	.05
Total.....	100.00

As air weighs 1.2926 grams per liter at 0° C. under normal atmospheric pressure (Van Nostrand's Chemical Annual, 1913, p. 3), 1 cubic foot (28.32 liters) of air at 20° C. will weigh $1.2926 \times 28.32 \times \frac{273}{293} = 34.1077$ grams, and will have the following composition:

<i>Composition of 1 cubic foot of air.</i>	
	Grams.
Nitrogen (N ₂).....	25.7547
Oxygen (O ₂).....	7.8959
Argon (A).....	.4400
Carbon dioxide (CO ₂).....	.0171
Total.....	34.1077

The air is assumed to be at 760 millimeter pressure.

4. The heat of combustion of the coal selected was determined as 7,595 calories per gram.

5. The product of combustion whose specific heats must be known are: Carbon dioxide, water vapor, nitrogen, sulphur dioxide, argon, and ash.

Equations for the average molecular specific heats at constant volume over a range from 0° C. to about 2500° C. of all the gases

named are given in the "Tables annuelles internationales de constantes et données numériques," volume 1, 1910, page 56.

These equations are:

$$\text{CO}_2, K=6.8+0.0033t-0.00000095t^2+0.000000001t^3.$$

$$\text{SO}_2, \text{ Same as } \text{CO}_2.$$

$$\text{A } K=2.977.$$

$$\text{N}_2, K=4.900+0.00045t.$$

$$\text{H}_2\text{O } K=6.065+0.0005t+0.0000000002t^2.$$

t =final temperature in ° C.

These are converted to normal specific heats by dividing each by its molecular weight (taken as 44, 64, 39.9, 28, and 18, respectively), giving:

$$\text{CO}_2, K=0.1545+0.000075t-0.000000022t^2+0.000000000002t^3.$$

$$\text{SO}_2, K=0.1063+0.000052t-0.000000015t^2+0.000000000002t^3.$$

$$\text{A } K=0.0746.$$

$$\text{N}_2, K=0.1750+0.000016t.$$

$$\text{H}_2\text{O } K=0.3369+0.000028t+0.000000000011t^2.$$

The specific heat of ash is taken as 0.21.

CALCULATION OF THE COMBUSTION OF COAL.

The constituents of the 1 gram of coal given above will combine with oxygen from the air according to the following table:

Combination of constituents of 1 gram of coal with oxygen from the air.

Constituent.	Ratio of combination.	Weight present.	Weight of oxygen used.	Product.	Weight of product.
		<i>Gram.</i>	<i>Grams.</i>		<i>Grams.</i>
H ₂	1 to 8.....	0.0529	0.4232	H ₂ O.....	0.4761
C.....	3 to 8.....	.7578	2.0206	CO ₂	2.7786
S.....	1 to 1.....	.0153	.0153	SO ₂	.0306
N ₂		.0153		N ₂	.0153
Ash.....		.0669		Ash.....	.0669
O ₂		.0918	(*)	(*)	(*)

* Used in above combinations.

The total oxygen necessary is 2.4593 grams. Of this, 0.0918 gram is furnished by the coal itself, leaving 2.3675 grams to be furnished by the air. One cubic foot of air at 20° C. contains 7.8959 grams of oxygen, and consequently 1 cubic foot of air will oxidize $\frac{7.8959}{2.3675} = 3.3351$ grams, or 0.118 ounce of coal. (1 gram = 0.03527 ounce).

The amount of this coal to combine completely with all the oxygen in 1 cubic foot of air at 20° C. and 760 millimeters of mercury pressure is therefore 0.118 ounce.

On page 50 of Bulletin 20, Bureau of Mines, a similar calculation gave a value of 0.123 ounce per cubic foot. The coal used there had a higher oxygen content than the one considered here, and the calcu-

lation was made on the basis of air at 0° C., both differences combining to give a higher value in that case.

The products of combustion of 3.3351 grams of coal are indicated in the following table:

Products of combustion of 3.3351 grams of coal.

Original constituents of coal and air.	Weight.		Final products.	
	Coal, grams.	Air, grams.	Constituent.	Weight, grams.
H ₂	0.1764		H ₂ O.....	1.557
O ₂	.3062	7.8669		
C.....	2.5274		CO ₂	9.2844
CO ₂		.0171	CO.....	
N ₂	.0510	25.7547	N ₂	25.8057
S.....	.0510		SO ₂	.1020
Ash.....	.2231		Ash.....	.2231
A.....		.4400	A.....	.4400
Total.....	3.3351	+ 34.1077	—	37.4628

The heat produced would be $3.3351 \times 7595 = 25330$ calories.

The attainment of the maximum temperature may be divided into two stages: 1, The raising of the water from 20° C. to 100° C. and its conversion of steam; 2, the raising of the steam from 100° C. to t° C. and of the other products from 20° C. to t° C.

The heat used in part 1 is given by the equation:

$$Q_1 = 1.5876 \times 80 + 1.5876 \times 536 = 978 \text{ calories.}$$

For part 2:

$$Q_2 = 25330 - Q_1 = 24352 = AK_A t_1 + BK_B t_2 + CK_C t_3 + \dots \text{ where } A, B, C, \text{ etc., are the weights of the different material, } K_A, K_B, K_C, \text{ etc., are their specific heats. } t_1, t_2, t_3, \text{ etc., are the temperatures through which the materials are to be heated.}$$

Substituting values obtained we have:

$$\begin{aligned} 24352 = & 1.5876 (0.3369 + 0.000028t + 0.00000000011t^2) (t - 100) \\ & + 9.2844 (0.1545 + 0.000075t - 0.000000022t^2 + 0.00000000002t^3) (t - 20) \\ & + 0.1020 (0.1063 + 0.000052t - 0.000000015t^2 + 0.00000000002t^3) (t - 20) \\ & + 25.8057 (0.1750 + 0.000018t) (t - 20) \\ & + 0.440 \times 0.7461 (t - 20) + 0.2231 \times 0.21 (t - 20). \end{aligned}$$

Performing indicated operations:

$$0.0000000000363t^4 - 0.0000002079t^3 + 0.001163t^2 + 6.550t - 24526 = 0.$$

Solution of this equation gives:

$$t = 2748^\circ \text{ C.} = 4978^\circ \text{ F.}$$

The pressure developed will be due to three causes: 1, The products of combustion will occupy more than 1 cubic foot at 20° C. and 760 millimeters; 2, the pressure will rise in proportion to the absolute temperature; 3, the pressure will be increased by the dissociation at high temperatures.

1. The volume of the gaseous products of combustion will be greater than 1 cubic foot at 20° C. by the sum of (a) the volume of

the nitrogen released from the coal; (b) the volume of the water vapor (calculated as a gas at 20° C.) released from the coal, and (c) one-half the volume of water vapor (similarly calculated) produced by combustion of atmospheric oxygen. The volume of the ash is negligible. (a) The weight of the nitrogen released from the coal is 0.0510 gram. (b) The weight of water vapor released from the coal is one and one-eighth times the weight of the oxygen in the coal—0.3445 gram. The hydrogen used is one-eighth of the weight of the oxygen, or 0.0383 gram, leaving 0.1381 gram of hydrogen to combine with oxygen from the air. (c) One-half the weight of water produced by combustion with air will be $0.1381 \times \frac{9}{2} = 0.6214$ gram. The total weight of water produced is $0.6214 + 0.3445 = 0.9659$ gram.

The weights of nitrogen and water vapor are converted to volumes by dividing by the weight of a liter of the gas, converting to cubic feet, and correcting to 20° C. as follows:

$$N_2 = \frac{.0510}{1.2507} \times \frac{1}{28.32} \times \frac{293}{273} = .001545 \text{ cubic foot.}$$

$$H_2O = \frac{.9659}{1.7444} \times \frac{1}{28.32} \times \frac{293}{273} = .029416 \text{ cubic foot.}$$

The total volume will be 1.0310 cubic feet or, Pressure at 20° and 760 millimeters = 1.031 atmospheres absolute.

2. Pressures produced by temperature are:

$$1.031 \times \frac{3021}{293} = 10.630 \text{ atmospheres absolute.}$$

= 142 pounds per square inch above atmospheric pressure.

3. Values for the dissociation of all the gases involved were not available but dissociation is an important factor with temperatures higher than 2000° C. Thus, at 2700° C. pure carbon dioxide is approximately 30 per cent dissociated when under a pressure of ten atmospheres. These and other considerations show that the pressure obtainable by explosion of coal dust can not be accurately calculated in the present state of our knowledge of the physical laws involved.

CALCULATION FOR METHANE.

In determining methane a new question arises. The volume of the original methane can not be neglected; that of the coal dust could be. The combustion of one cubic foot of a methane and air mixture will be considered here. Methane combines with oxygen in the ratio of 1:4 by weight and 1:2 by volume. The final volume is the same as the original volume provided the water formed remains in the gaseous state.

One cubic foot of the mixture has the following composition:

Analysis of 1 cubic foot of methane and air mixture.

	Per cent by volume.	Weight in 1 cubic foot grams.
N ₂	70. 69	23. 3248
O ₂	18. 96	7. 1499
CH ₄	9. 48	1. 7930
A.....	. 85	. 3998
CO ₂	. 03	. 0157
	100. 00	32. 6832

The weights are figured from the weight per liter as given in Van Nostrand's Chemical Annual, 1913, page 3, and are converted to 20° C. The products of combustion will be:

Products of combustion.

	Grams.
N ₂	23. 3248
CO ₂	4. 9343
H ₂ O.....	4. 0243
A.....	. 3998
Total.....	32. 6832

The heat of combustion of methane is given by Berthelot as 13,344 calories per gram, the water being liquid.

Heat generated in above reaction:

$$13344 \times 1.7930 = 23926 \text{ calories.}$$

The heating of the gases to t degrees is in two parts as before:

1. Heating of water to 100° C. and conversion to steam.

$$Q_1 = 4.0243 \times 80 + 4.0243 \times 536 = 2479 \text{ calories.}$$

2. Heating of steam from 100° to t ° and remaining gases from 20° to t °.

$$Q_2 = 23926 - Q_1 = 21447 = AK_A t_1 + BK_B t_2 + \dots$$

$$21447 = 4.0243 (0.3369 + 0.000028 t + 0.00000000011 t^2) (t - 100)$$

$$+ 4.9343 (0.1545 + 0.000075 t - 0.000000022 t^2 + 0.00000000002 t^3) (t - 20)$$

$$+ 23.3248 (0.1750 + 0.000016 t) (t - 20) + 0.3998 \times 0.7461 (t - 20)$$

Simplifying:

$$0.000000000054 t^4 - 0.0000001130 t^3 + 0.000858 t^2 + 6.472 t - 21685 = 0.$$

Solution of this equation gives:

$$t = 2483^\circ \text{ C.}$$

$$= 4501^\circ \text{ F.}$$

Neglecting dissociation the pressure developed is due solely to temperature and is equal to:

$$\frac{2756}{293} = 9.406 \text{ atmospheres absolute.}$$

$$= 124 \text{ pounds per square inch above atmospheric pressure.}$$

The following table shows the values obtained:

	Coal dust.	Gas.
Maximum temperature.....	2700° C.	2500° C.
Do.....	5000° F.	4500° F.
Maximum pressure.....	10. 6 atm. abs.	9. 4 atm. abs.
Do... pounds per square inch...	142 above atm.	124 above atm.

SELECTED BIBLIOGRAPHY ON THE EXPLOSIBILITY OF COAL DUST.

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- General specifications for rock-dusting machinery: Vol. 9, April 15, 1916, pp. 672-673; Specifications for a machine similar to one used at experimental mine, Bureau of Mines.
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- STRZELECKI, PERCY, List of fatal and nonfatal explosions of fire damp or coal dust and barometer, thermometer, etc., readings for the year 1914: *Trans. Inst. Min. Eng.*, vol. 48, 1915, pp. 679-685.
- THORNTON, W. M., The influence of pressure on the electrical ignition of methane: *Electrician*, vol. 77, September 8, 1916, pp. 775-779. The compression of an explosive mixture increases its inflammability by condenser sparks and lowers it when the sparks are impulsive. Circuit-breaker sparks have same igniting power over a long range of pressure.

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- YUVENALIEFF, N., On the liberation of gas in mines: Coll. Guard., vol. 112, July 7, 1916, pp. 17-18. Investigation to determine the relation between gas emission and microseismic vibration of the earth. Translated from Gorno-Savodakoie Dielo.

SELECTED BIBLIOGRAPHY ON THE EXPLOSIBILITY OF CARBONACEOUS DUSTS.

By ALAN LEIGHTON.

The bibliography is arranged in three parts, as follows: Part 1, literature dealing with the explosibility of dusts other than coal dust in mines; part 2, literature dealing with experimental work on the explosibility of coal dust; part 3, literature dealing with coal-dust experiments conducted by foreign governments.

The papers in part 1 are arranged alphabetically according to the type of dust, all articles under each head being arranged alphabetically by author. The papers in part 2 dealing with the explosibility of coal dust are arranged by author. Reports dealing with work conducted by foreign governments, comprising part 3, are grouped by countries. There are included in this bibliography about 25 reviews from the bibliography in Bulletin 20, Bureau of Mines, 1911, page 184.

PART 1.—EXPLOSIBILITY OF MISCELLANEOUS DUSTS.

ALUMINUM DUST.

- BAMBERGER, M., and VAN JUPTNER, H. [An aluminum explosion]: *Ztschr. angew. Chem.*, Jahr. 26, 1913, pp. 353-355. Abstracted, *Chem. Abs.*, vol. 7, 1913, pp. 3416, 3644. Note, *Engineering*, vol. 96, 1913, p. 232. An account of an explosion of aluminum in an Austrian steel works. Molten aluminum was being poured into cold water to granulate it. Author concludes that the explosion was caused by the generation of excessive steam pressure within the mass of fused metal after entering the water.
- EDELMAN, C. [Explosions in the aluminum-bronze industry]: *Chem. Ztg.*, Jahrg. 30, 1905, pp. 925-926, 951-952. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 25, 1906, p. 1099. An account of experimental work to determine the electrical conductivity of layers of aluminum dust 8 millimeters thick. Dust is practically a nonconductor for voltages less than 350, but conducts well for higher. Author concludes that it should be easy to prevent accumulation of charges of static electricity near machines employed in manufacturing the powder.
- GUILLET, L. [Manufacture of aluminum foil and powder]: *Rev. métall.*, t. 9, 1912, pp. 147-159. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 31, 1912, p. 339; *Chem. Abs.*, vol. 6, 1912, p. 730. An account of methods employed in manufacturing aluminum foil and powder. Good description of apparatus given.
- KAYSER, — [Explosibility of aluminum dust]: *Ztschr. off. Chem.*, Jahrg. 3, 1897, p. 93. Not reviewed.
- KOHN-ABREST, E. [Aluminum powder and the oxidation of aluminum]: *Bull. Soc. chim. France*, t. 31, 1904, pp. 232-239. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 23, 1904, p. 324. Aluminum powder in contact with aluminum or aluminum hydroxide becomes oxidized, action being especially rapid in an ammoniacal medium. If aluminum hydroxide be precipitated from a chloride solution by ammonia and aluminum powder be added, the latter is soon completely converted into a white gelatinous mass, probably a suboxide.

- KOHN-ABREST, E. [Oxidation of aluminum powder]: *Compt. rend.*, t. 141, 1905, pp. 323-324. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 24, 1905, p. 906. Aluminum powder heated for 10 minutes in a tube open at both ends shows no sign of oxidation unless the temperature be above 400° C. Rate of oxidation increases as the temperature is raised to 635°, is constant to 750°, increases again from 800° to 1,000°, and is constant to 1,200°. The metal begins to lose its luster at 500°. When heated one hour at 1,000°, the weight of oxygen absorbed is a maximum.
- KOHN-ABREST, E., and CARVALLO, J. [Thermal phenomena accompanying the action of water on aluminum powder]: *Compt. rend.*, t. 148, 1909, pp. 410-412. Abstracted, *Chem. Abs.*, vol. 3, 1909, p. 1359. Aluminum powder heated to 83° C. with water is oxidized by it with heat evolution; it then absorbs heat, probably during the hydration of the oxide already formed.
- RICHTER, N. M. [Explosibility of aluminum dust]: *Chem. Ztg.*, Jahrg. 30, 1906, p. 324. General article on the explosibility of aluminum dust, with pictures of "mills" designed to form artificial dust clouds and ignite them with electric sparks. Author believes that the hydrogen and oxygen liberated from moisture that may be present are a big factor in explosibility.
- [Explosions in the aluminum-bronze industry]: *Chem. Ztg.*, Jahrg. 30, 1906, pp. 324-326; Jahrg. 32, 1908, p. 136. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 25, 1906, p. 430; *Chem. Abs.*, vol. 11, 1908, p. 1491. Traces a number of explosions to electric sparks proceeding from brushes used in elevating and polishing the dust; gives a number of precautions to be taken.
- STOCKMEIER, —. [Causes of explosions in the manufacture of aluminum-bronze powder]: *Ztschr. Untersuch. Nahr- u. Genussmittel*, vol. 2, 1899, pp. 49-61, *Bayer Gewerbezeitung*, vol. 11, 1898, p. 261. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 18, 1899, p. 280. States that the powder is stable to percussion and friction, but explodes readily if potassium chlorate be added. Shaken in a flask with air, it can be exploded readily by an electric spark. It is hygroscopic, taking up 1.4 per cent of moisture from saturated air. Many precautions are suggested to lessen danger during manufacture.
- [Explosions of aluminum-bronze powder]: *Chem. Ztg.*, vol. 30, 1906, p. 580. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 25, 1906, p. 639. A slight elevation of temperature in washing out the gum may cause a sudden evolution of hydrogen. The powder usually contains 2 to 3 per cent of water. Under most favorable conditions in mills not more than one-quarter of the theoretical amount of hydrogen is given off. Author concludes that there is little danger of a hydrogen explosion in mills manufacturing aluminum-bronze powder.
- [Explosibility of aluminum dust]: *Jahresber. des bayer. Gewerbemuseums*, 1904, —; *Ausstellungszeitung und technol. Mitteil. des bayer. Gewerbemuseums*, 1905, p. 13. Paper describes various forms of apparatus used by Stockmeier for determining explosibility of aluminum dust.
- [Explosibility of aluminum dust]: *Ztschr. angew. Chem.*, Jahrg. 19, 1906, p. 1665. States that ignition temperature of ordinary aluminum dust powder is 480° to 490° C.; finest dust may be ignited at 230°. Sources of danger are air flotation and sparks of frictional electricity. Any hydrogen produced is quickly dissipated and is therefore not dangerous. Method used to determine ignition temperature of dust is not described.
- [Explosibility of aluminum dust]: *Chem. Ztg.*, Jahrg. 30, 1906, p. 385. A criticism of a paper by Richter in which the latter concludes that the oxygen and hydrogen liberated from moisture present in the powder are probably the important factor in an explosion.
- ZINK, R. J. [Aluminum-dust explosions]: *Chem. Ztg. Jahrg.* 35, 1911, pp. 1370-1372. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 31, 1912, p. 30; *Chem. Abs.*, vol. 7, 1913, p. 750. Refutes the statement by Richter that gases liberated from moisture

ties of aluminum carbide may be present and be a source of danger when moisture is absorbed; also suggests that mills be sealed with a porous material; gases would diffuse through this and it would give way in an explosion, preventing further damage.

COAL DUST EXPLOSIONS IN SURFACE PLANTS.

[NOTE.—The Bureau of Mines has not yet published a report on coal-dust explosions in industrial plants aboveground, but has investigated a number of such explosions or inflammations in which the primary cause has been the permitting of dust to enter the air of the structure—instead of keeping the dust in a closed circuit—and by back-firing through the pipe system after cessation of work. The causes of ignition have variously been an open flame, an electric grounding, back-firing, and overheating, or spontaneous firing in a bin or pipe prior to contact by a dust cloud. In an old semianthracite breaker, the dust was ignited by an explosive used in scrapping some machinery.—G. S. RICE.]

COAL AGE, Coal-dust explosion above ground, British Inspector's Report, 1911: Vol. 3, 1913, p. 220. Sparking of an electric motor in grinding house ignited coal dust inside the motor and the flame spread outside until violent explosion resulted.

— Coal-dust explosion above ground: Vol. 3, 1913, p. 609, note. An account of an explosion at Homestead, Pa. Five men were shoveling coal into stoker cars from a pit when the dust ignited, killing them all.

— Powdered-coal fire: Vol. 7, 1915, p. 891. Fire caused by ignition of coal dust which leaked from a conveyor and was blown by furnace door.

COLLIERY GUARDIAN, Dust explosions in briquette works: Vol. 68, 1894, p. 626. Brief summary of report of German Lignite Industry Association.

— Dust explosions in briquette works and means for their prevention: Vol. 73, 1897, p. 717. From notes by A. Scheele on a visit to briquette factories of Senftenberg lignite district.

ENGINEERING NEWS, Coal-dust explosion: Vol. 49, 1903, p. 205. At Edison cement plant conveyors carry coal from storage bins to grinding house, where it is pulverized. Fire started in one bin and burning coal was carried to grinding house, where coal-dust-laden atmosphere ignited.

— Coal-dust explosion: Vol. 65, 1911, p. 58, note. Account of an explosion in a Colorado cement plant. Two men were killed and seven injured.

GRIFFITH, D., Dust explosions; a peculiar explosion on a tippie at the Crested Butte mine, Colorado: Mines and Minerals, vol. 18, 1898, p. 496. Dust ignited by lamp.

HOLLY, L. F., Coal-dust explosions in cement mills: Concrete-Cement Age, vol. 21, 1915, p. 3. Not reviewed.

MCNEIL, JOHN, Prevention of accidents in coal mines: Coal Age, vol. 4, 1913, p. 43. Coal dust raised in a tippie by some runaway cars became ignited.

OAKLEY, SAMUEL, An explosion in a coal box: Colliery Engineer, vol. 12, 1891-1892, p. 212.

RAILWAY AGE GAZETTE, Powdered-coal-plant explosion: Eng. News, vol. 70, 1913, p. 223. In the coal-grinding mill of a cement plant a bit of waste caught fire. A hissing sound like escaping steam accompanied the fire, which traveled swiftly back and forth through the building several times in layers like a train of powder with no report. All the men were burned to death.

COCOA DUST.

ENGINEERING NEWS, Cocoa-dust explosion: Vol. 71, 1914, p. 812. A note on a cocoa-dust explosion in which loss of life occurred.

REID, W. F., Manufacture of linoleum: Jour. Soc. Chem. Ind., vol. 15, 1896, p. 76. A thorough treatment of the manufacture of linoleums. The author says: "Cork is ground, producing a very light powder easily suspended in air and subject to explosion from chance sparks from the machinery. I would rather handle dynamite in bulk than loose ground cork."

CORN DUST.

ENGINEERING NEWS, Explosions of corn dust: Vol. 64, 1910, p. 165. An account of a corn-dust explosion.

DEXTRINE DUST.

JACKSON, J., Explosion of dextrine works: Jour. Soc. Chem. Ind., vol. 32, 1913, p. 1080; Engineering, vol. 96, 1913, p. 99, note. An account of an explosion.

RUDGE, W. A. D., The electrification produced during the raising of a cloud of dust: Proc. Royal Soc. London, A vol. 90, 1914, pp. 256-272. Author refers to a similar paper by him in the Philosophical Magazine, May, 1913. He shows experimentally that the raising of a dust cloud is accompanied by the production of large charges of electricity. The sign of the charge depends on the nature of the material used; the total electrification of dust and air is zero. Friction between particles of similar materials apparently causes enough electrification to account for charges observed. An unmeasurable amount of dust can produce an easily measurable charge. These charges can account for electrical phenomena of sand storms and for lightning flashes often seen above active volcanoes.

FLOUR DUST.

BETH, W. F. L., [Removing dust from the purifying machines of flour mills]: Rauch und Staub, December, 1914; translation by O. L. Schwartz, Bureau of Mines library, Pittsburgh. Treats of a dust collecting and filtering device designed to remove danger of explosion and fire.

DINGLER'S POLYTECHNISCHES JOURNAL, [Explosions in flour mills; theoretical—Miscellaneous]: Jahrg. 206, 1872, p. 417. Abstracted, Jour. London Chem. Soc., vol. 26, p. 420. There are two explanations of the explosibility of flour dust: 1, rapid combustion of the finely divided flour; 2, ignition of gases furnished by the decomposition of the flour. Flour and bran intimately mixed at a temperature of 450° C. give off a gas which, mixed with nine volumes of air, forms an explosive mixture. Author says candle flame will ignite flour-dust cloud.

ENGINEERING, Explosion at the Tradeston flour mills: Vol. 14, 1872, p. 164. Copy of a report on the explosion.

— Explosions in flour mills: Vol. 33, 1882, p. 206. An account of an explosion, with notice of the little appreciated dangers of such explosions.

— Explosive dust: Vol. 35, 1883, p. 376, note. Calls attention to a paper by T. W. Tobin, of Kentucky Polytechnic Society, who had investigated flour-mill explosions. The paper was read before the Fire Underwriters Association of Chicago.

— Carbonaceous-dust explosions: Vol. 93, 1912, p. 877. Editorial referring to report of H. M. Inspector of Factories and recommendations for precautionary measures to be taken to reduce number of flour-mill explosions.

ENGINEERING NEWS, A flour-mill explosion: Vol. 66, 1911, p. 159, note. An account of an explosion in which dust is supposed to have become ignited by sparks from an electric motor.

MINING AND SCIENTIFIC PRESS, Dust explosions in flour mills: Vol. 25, p. 275. Not reviewed.

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PECKHAM, S. F., Explosion of the flour mills at Minneapolis: *Chem. News*, vol. 40, 1879, pp. 59-61.

——— Dangerous dusts and their explosions: *Jour. Soc. Chem. Ind.*, vol. 26, 1907 p. 245. An account of the big explosion in Minneapolis. Also an interesting general article.

SHILLADAY, J. R., and NEWELL, W., The Husted mill explosion and explosions in flour and cereal mills: Dept. of Labor, N. Y., Bull. 56, 1913, pp. 393-399.

SMITH, W., Flour-mill explosions and dangerous dusts: *Jour. Soc. Chem. Ind.*, vol. 25, 1906, p. 54. An interesting historical article.

GRAIN DUST.

AMERICAN MILLER, Grain-dust explosions: July, 1916, p. 566.

DEDRICK, B. W., TEHER, R. B., and PRICE, D. J., Grain-dust explosions: Bull. 681, Dept. of Agriculture, 1918, 54 pp.; Bull. 26, Eng. Exp. Sta., Penn. State College, 1918, 54 pp. Describes tests under actual working conditions.

ENGINEERING NEWS, Grain-dust explosion: Vol. 60, 1908, p. 444; editorial, p. 450. Detailed description of an elevator explosion and an editorial urging investigation of dust explosions to develop preventive methods.

——— Explosion of grain dust: Vol. 63, 1910, p. 27, note.

——— Explosion of grain elevator: Vol. 70, 1913, p. 88; editorial, p. 223. Account of an explosion in which 33 lives were lost.

——— Grain-dust explosion: Vol. 70, 1913, p. 574. Explosion caused by bits of grit, etc., which got into the mill, causing sparks, that ignited floating dust in the rooms.

——— Grain-elevator explosion: Vol. 71, 1914, p. 863. Explosion on bin floor, resulting in wreck of large structure.

PRICE, D. J., and BROWN, H. H., Preliminary report on explosibility of grain dusts: *Jour. Ind. Eng. Chem.*, vol. 6, 1914, pp. 934-937. Gives pressures obtained in Frazer apparatus by the explosions of a considerable number of dusts; also lists usual causes of grain-dust explosions.

——— Explosions of grain dusts: A preliminary report of the explosibility of grain dusts, being the results of the cooperative investigation by the Millers' Committee of Buffalo, N. Y., under the direction of the United States Bureau of Mines.

PRICE, DAVID J., and MCCORMICK, E. B., Dust explosions and fires in grain separator in the Pacific Northwest: Bull. 379, Dept. of Agriculture, 1916, 22 pp. Not reviewed.

GRAHAMITE DUST.

ENGINEERING, Grahamite explosion: Vol. 57, 1895, p. 509. Describes two dust explosions resulting from blasting the material.

FONTAINE, W. M., Notes on West Virginia asphaltum deposits: *Am. Jour. Sci.*, ser. 3 vol. 6, 1873, p. 409. Notes explosibility of grahamite dust.

GLENN, WILLIAM, Mine explosions generated by grahamite dust: *Trans. Am. Inst. Min. Eng.*, vol. 24, 1894, pp. 195-207, 1898. Describes explosions of grahamite dust in mine at Richie, W. Va., February 9, 1871, and February 25, 1873.

LAMPBLACK.

ENGLER, C., Dust explosions: *Chem. Ind.*, vol. 8, p. 171; *Eng. News*, vol. 14, 1885, p. 299. Abstracted, *Jour. Soc. Chem. Ind.*, vol. 4, 1885, p. 487. Experiments undertaken to determine whether inflammation of dust floating in air can take place when dust is incapable of engendering combustible gas under generation of heat. Work was carried out to investigate explosions of carbon dust in the manufacture of lampblack. Conclusion reached is that a carbon dust satisfying above conditions is capable of rendering explosive a mixture of air and a hydrocarbon gas when proportion of gas would not suffice to engender flame under ordinary circumstances. Author could not ignite a mixture of lampblack in air.

PAPER DUST.

[Explosion of paper dust]: *Ztschr. ges. Schiess-Sprengstoffw.*, Jahrg. 9, 1911, p. 135; *Chem. Abs.*, vol. 8, 1914, p. 1872; *Rauch und Staub*, 1914, Jahrg. 4, No. 5. Translated by O. L. Schwartz, Bureau of Mines library, Pittsburgh. Experiments at Liévin showed paper dust to be as explosive as coal dust containing 30 per cent volatile matter.

SAWDUST.

ENGINEERING NEWS, Explosion of sawdust: Vol. 64, 1910, p. 189.

—— Sawdust explosion: Vol. 69, 1913, p. 329, note.

SOAP DUST.

PECKHAM, S. F., The dust explosions at Minneapolis: *Jour. Soc. Chem. Ind.*, vol. 26, 1907, p. 245. An account of soap and flour-dust explosions. Gives experiments conducted by Peck with his apparatus. See Peck, L. W., Explosions of combustible dusts, under Miscellaneous dusts.

STARCH DUST.

ENGINEERING NEWS, Starch-dust explosion: Vol. 63, 1910, p. 297. Explosion alleged to have been caused by overheating of a starch kiln.

GROSVENOR, W. M., A peculiar dust explosion: *Jour. Soc. Chem. Ind.*, vol. 33, 1914, p. 60. Explosion caused by taking lantern into a starch drier which was being cleaned. Author was unable to obtain a violent starch explosion even by using a detonator to ignite dust.

SUGAR DUST.

ENGINEERING NEWS, Sugar explosion: Vol. 59, 1908, p. 595. Note on an explosion caused by sparks from a dynamo.

PELLET, I. [Sugar-dust explosions]: *Suc. Belge*, t. 41, pp. 378-379. Explosions of sugar dust are generally caused by sparks of static electricity.

WHEELER, R. V. [The explosibility of sugar dust]: *Deut. Zuckerind*, Jahrg. 40, 1915, p. 533. As small a source of heat as a match may ignite a cloud of sugar dust. A cloud of sugar or dextrine blown against a hot surface may explode. Minimum ignition temperature for sugar dust is about 500° C., the same for dextrine dust, and 630° for melted sugar.

THRESHING MACHINES.

PRICE, D. J., and GOODENOW, W. G., Static as a cause of wheat-rust explosives in threshing machines: *Am. Thresherman and Farm Power*, vol. 20, 1917, pp. 5, 56.

WEEKLY NEWS LETTER, Explosions in threshing machines: Department of Agriculture, May 31, 1916, 8 pp.

WASTE EXPLOSIONS

ENGINEERING NEWS, Prevention of dust explosions when waste is being fed into furnaces: Vol. 71, 1914, p. 1129. Mentions several accidents due to the formation of a back draft from furnace and gives a mechanical arrangement for preventing them.

MISCELLANEOUS DUSTS.

Under this head are grouped general articles on dust explosions which treat of more than one kind of dust.

BROWN, H. H., Inflammability of carbonaceous dusts: *Jour. Ind. and Eng. Chem.*, vol. 9, 1917, p. 269. Explosibility tests with Fraser apparatus of a large number of dusts.

93, 1912, pp. 877-878. Data on dust explosions in factories, causes, and suggestions on prevention.

ENGINEERING NEWS, The modus operandi of dust explosions: Vol. 60, 1908, p. 451.

ENGLER, C., On explosions caused by dust: Chem. Ind., vol. 8, 1885, p. 171; Eng. News, vol. 14, 1885, p. 299. Abstracted, Jour. Soc. Chem. Ind., vol. 4, 1885, p. 487. Author ignited clouds of flour, sulphur, naphthalene, and colophonium; could not ignite a soot cloud, but could ignite a particularly unflammable mixture of gas and air when soot was present.

HOLLAND, C. [General nature of gas and dust explosions and the influence of moisture on the same]: Ztschr. ges. Schiess-Sprengstoffw., Jahrg. 7, 1912, p. 135. Discussion of gas and dust explosions and influence of moisture.

JOURNAL OF THE SOCIETY OF CHEMICAL INDUSTRY, Dust explosions (Annual Report of H. M. Chief Inspector of Factories, 1911): Vol. 31, 1912, p. 699. Contains a table classifying the various factories according to the dusts likely to be present, and marking with * those in which explosions had occurred during the year.

— Dust explosions (Annual Report of H. M. Chief Inspector of Factories, 1912): Vol. 32, 1913, p. 764. Gives accounts of seven dust explosions and states that Haydon (same, vol. 32, 1913, p. 447) has found that dusts in oil mills are explosive.

— Dust explosions (Section of Annual Report of the Chief Inspector of Factories and Work Shops, 1914): Vol. 34, 1915, p. 1230. Refers to tests by R. V. Wheeler showing that samples of dust from paper-tube works yielded from 24 to 54 per cent ash, and dust from rag clippings 27 to 77 per cent ash; classes those yielding less than 32 per cent as dangerous. Tapioca dust yielding 2 per cent ash is not dangerous, as 30 per cent of gas evolved on heating is carbon dioxide. Dusts from the mixing and spicing rooms of a cattle-food factory and from grinding room of a provender mill proved to be dangerous. Pitch dust is more inflammable than coal dust and is nearly as dangerous as sugar. Mentions two explosions in diazo-dye works using aniline and naphthalene bases, and refers to a violent explosion of picric-acid dust.

LANG, W. R., Dust explosions and the surface areas of certain finely divided combustible solids: Proc. Chem. Soc. No. 168, 1911. Abstracted, Jour. Soc. Chem. Ind., vol. 32, 1913, p. 808. Ignitions were obtained with lycopodium, maize starch, coal dust, pyrophoric carbon, and pyrophoric-iron dusts using an ignition apparatus consisting of a 7-foot glass tube containing an ignition coil.

MORGAN, J. D., Dust explosions: Proc. Inst. Min. Eng., vol. 44, 1912, p. 145. Not reviewed.

— Experiments on dust explosions in tubes: Engineering, vol. 98, 1914, p. 209. Describes experiments in which pressure curves of dust explosions in small tubes were recorded. Apparatus consisted of an ignition box or chamber in which a dust cloud was blown up and ignited; a tube was connected to this box and flame from preliminary explosion raised and ignited dust in tube.

PECK, L. W., Explosions from combustible dusts: Pop. Sci. Mo., vol. 14, 1878-1879, pp. 159-166. Dust clouds ignited by an apparatus consisting of a hand bellows, Bunsen burner, and two boards nailed into the shape of a V, the dust being placed on a table inside intersection of boards. Apparatus was introduced into a box and explosions obtained were strong enough to raise lid of box when two men stood on it. See also article by S. F. Peckham classified under "Explosibility of soap dusts."

PECKHAM, S. F., The dust explosions at Minneapolis and other dust explosions: Chem. Eng., vol. 7, 1908, pp. 146-151, 194-197; Jour. Soc. Chem. Ind., vol. 26, 1907, pp. 244-245; Am. Jour. Sci., vol. 16, No. 3, 1878, pp. 301-306; London Jour. Sci., vol. 16, p. 666. Deals with explosions of soap, flour, starch, sugar, rice, coal, planing-mill, furniture, and asphaltum dusts.

view, No. 125, March 25, 1878, p. —. A general popular article on dust explosions. SMITH, W. S., and JACKSON, J., Factory-dust explosions: Jour. Soc. Chem. Ind., v 31, 1912, p. 559. An account of dust explosions in factories grinding wheat beans, etc.

STRAUCH, —, [Dust explosions, their nature and prevention]: Rauch and Staub, October, 1914. Translated by O. L. Schwartz, U. S. Bureau of Mines Library, Pittsburgh. Interesting general article. Gives some theoretical figures on heat and pressures generated by burning starch.

TOBIN, T. W., Explosive and dangerous dusts: Chem. News, vol. 47, 1883, p. 14. Explosions obtained by dropping dusts down a 7-foot shaft onto a lighted Bunsen burner. Numerous perforations were made in the shaft to insure plenty of air which author said was necessary in order to obtain good ignitions.

WHEELER, R. V., Explosive dusts classified, sub. article British letter: Coal Age vol. 4, 1913, p. 618; Engineering, vol. 95, 1913, p. 606; Coll. Guard., April 4, 1913, p. 696. About sixty dusts are classified under three heads: 1, Dust likely to ignite and propagate flame readily under factory conditions; 2, dusts requiring a large heat source for ignition; 3, dusts apparently not dangerous under usual factory conditions.

PART 2.—EXPERIMENTAL WORK ON THE EXPLOSIBILITY OF COAL DUST.

ABEL, F. A., Sur le rôle des poussières dans les explosions des mines: Ann. des mines series 7, vol. 20, 1881, pp. 125–159. Attempts to secure explosion of coal dust by means of a charge of 26 grams of powder in bottom of wooden box were negative the powder flame being as long as the flame obtained when dust was present.

— Some of the dangerous properties of dust: Proc. Roy. Inst. Great Britain, vol. 10, pt. 1, 1882, pp. 88–113. Mentions several explosions in flour mills and reviews coal-dust problem. Speaks of certain noncombustible dusts exerting a contact or catalytic action on gas mixtures.

— Some of the dangerous properties of dusts: Nature, vol. 26, 1882, pp. 19–22; Trans. Chesterfield and Derbyshire Inst. Eng., vol. 10, 1882, pp. 245–280. Abstract of lecture at Royal Institute.

AGUILLON, LOUIS, Expérience de M. le Professeur Abel sur le rôle des poussières dans les explosions des mines: Ann. des mines, t. 159, 1881, p. 121. Introductory notes and translation of report by Abel.

ASHWORTH, J., Review of the coal-dust question: Coll. Guard., vol. 69, 1895, pp. 399, 445. Extensive summary of the question from the beginning and the conclusions reached to date.

— Colliery explosions and coal dust: Coll. Guard., vol. 71, 1896, p. 305. Subtitle, "The occluded combustible gases, the ignition point of coal dust, and the after-damp."

— Coal-dust problem: Coll. Guard., vol. 83, 1902, p. 41. On ineffectiveness of watering.

— Notes on recent demonstrations of coal-dust phenomena: Trans. Inst. Min. Eng., vol. 36, 1908–1909, p. 366. Accounts of ignitions in mines.

— Coal dust: Mines and Minerals, vol. 32, November, 1911, p. 218. Discusses influence of percussion, compression, and detonation in causing and transmitting explosions.

— The combustion of oxygen and coal dust in mines: Coll. Eng., vol. 33, 1913, p. 709. A brief historical article.

- p. 38. Describes method of exploding coal dust in a large iron boiler, using a detonator; shows such explosions are prevented by passing steam or ice-cooled air into explosion vessel before firing detonator.
- BEDSON, P. P., Experiments illustrating the inflammability of coal dust and air: *Iron and Coal Trades Rev.*, vol. 80, June 3, 1910, p. 880. Describes experiments with various agents of ignition and various coal. Contains tables.
- BEDSON, P. P., and MCCONNELL, WILLIAM, Contributions to our knowledge of coal dust: *Trans. Fed. Inst. Min. Eng.*, vol. 7, 1894, pp. 27-53.
- BEDSON, P. P., and WIDDAS, H., Experiments illustrative of the inflammability of mixtures of coal dust and air: *Trans. Inst. Min. Eng.*, vol. 32, 1906-1907, pp. 529-531 and 597; vol. 34, 1907-08, p. 91; vol. 39, 1909-1910, p. 719; vol. 41, 1910-1911, p. 235. Abstracted, *Bull. 20, Bureau of Mines*, 1911, p. 129. Details of an apparatus, somewhat similar to Frazer apparatus, for determining explosibility of coal dusts. Description of experiments.
- BLACKETT, W. C., Combustion of oxygen and coal dust in mines: *Trans. Inst. Min. Eng.*, vol. 7, 1894, p. 259.
- Combustion of oxygen and coal dust: *Coll. Guard.*, vol. 105, April 18, 1913; *Iron and Coal Trades Rev.*, vol. 86, 1913, p. 615. General discussion of methods of laying dust; also various sources of danger.
- CADMAN, J., The ignition of coal dust by a naked light: *Trans. Inst. Min. Eng.*, vol. 38, 1909, p. 256; *Iron and Coal Trades Rev.*, vol. 79, 1909, p. 734. Coal dust fed into top of a vertical wooden gallery on to lighted burner. If dust was coarse, 150 to 180 mesh, flame did not reach top of 12-foot gallery, but if dust was 180-mesh flame reached top. With dust below 220-mesh flame issued 2 feet above top.
- The ignition of coal dust by means of electricity: *Trans. Inst. Min. Eng.*, vol. 39, 1909-1910, p. 93. Obtains ignition throughout a horizontal gallery 8 inches square and 12 feet long by blowing fuses under dust piles. Does not give details of construction or arrangement of gallery.
- Electric ignition of coal dust: *Iron and Coal Trades Rev.*, vol. 80, 1910, p. 293. A paper before South Staffordshire and Warwickshire Institute of Mining Engineering. Describes experiments on the ignition of coal dust in a small gallery.
- CLEMENT, J. K., and LAWRENCE, J. N., Laboratory determination of explosibility of coal dust and air mixtures: *Tech. Paper 141, Bureau of Mines*, 1917, 27 pp. Inflammability of various coals tested with Frazer apparatus made more sensitive by use of oxygen. Results are standardized against tests in the experimental mine.
- CLEMENT, J. K., and SCHOLL, L. A., Inflammability of Illinois coal dust: *Bull. 102, Bureau of Mines*, 1916, 76 pp. A detailed study of inflammability of bituminous dusts from Illinois mines. Part of the investigation in cooperation with the Illinois State Geological Survey and the Department of Mining Engineering of the University of Illinois.
- COAL AGE, Ignition temperature of coal: Vol. 1, 1911, p. 620. Notes that combustion of carbon occurs at temperature as low as 300° F. Temperature at which spontaneous ignition of fine coal dust can take place is given as 284° F. by Bedson, 356° F. by Fayal.
- Explosions: Vol. 1, 1911, p. 681. Refers to an article by James Ashworth, of Vancouver, Canada, in the South Wales Institute of Mining Engineers. Writer believes that gases held in coal under pressure are primary explosive; that detonation might take place and that a fall of rock, through resulting compression of air, could generate an explosion of coal dust. In another editorial detonating substances are defined as explosives that not only explode on percussion, but contain sufficient oxygen for complete internal combustion. Coal dust does not come under this head.

- Verner for inducing practice of shutting off fan at shot-firing time. Combats Verner's theory as violating principles of physics.
- Anthracite dust not explosive: Vol. 5, 1914, p. 554. An account of experiments on the explosibility of anthracite dusts at the experimental mine of the U. S. Bureau of Mines.
 - Explosibility of coal dust: Vol. 8, 1915, p. 302. An editorial on experiments showing that moisture does not prevent explosions of dust. Letter on same by J. Ashworth, p. 558; another letter by J. Verner, p. 642.
 - COLLIERY ENGINEER, Interesting experiments with coal dust: Vol. 15, 1894-1895, p. 68. From Iron and Coal Trades Review. Refers to experiments by Gwilym Jones at Lowe Duffryn collieries, Wales, August 6, 1894.
 - COLLIERY GUARDIAN, Coal-dust and colliery explosions: Vol. 66, 1893, p. 818. Author sceptical as to whether coal dust of itself can originate an explosion.
 - Coal-dust explosions: Vol. 68, 1894, p. 1037. Account of experiments by Galloway to prove theory of coal-dust explosibility and to convince British Government of need for further experimental work.
 - Coal-dust explosions in coal mines: Vol. 77, 1899, p. 720. Report of lecture by D. M. D. Stuart at Coleford; general and elementary.
 - The explosive qualities of coal dust: Vol. 98, 1909, p. 1255. Account of a lecture given at Ashby-de-la-Zouch, in which explosibility of dusts was demonstrated with a very small wooden gallery.
 - CRANE, W. R., Index of mining engineering literature: New York, 1912, 812 pp. Many references to dust explosibility. Many of same references are included in a bibliography of coal dust in Mines and Minerals, vol. 28, 1908, p. 444.
 - CUNYNGHAME, H. H., Data on ignition temperature on coals and tests of inflammability: Engineering, vol. 95, 1913, p. 164. Inflammability of dusts tested with a glass tube through which dusts were blown onto an electrically heated platinum coil.
 - DEAN, S., Inrush theory: Coal Age, vol. 3, 1913, p. 295. Claims that inrush theory is proved by experiments at Eskmeals.
 - DESBIEF, P., and CHANSSELLE, J., De l'influence des poussières charbonneuses dans les explosions de grisou: Bull. Soc. l'ind. min., ser. 2, vol. 4, 1875, p. 205. Review of discussions at meeting of society 1872-1875. Early observations of Du Souich and other French engineers. Describes experiments made by society in February, 1872, and March, 1875. Translation by W. Galloway in Iron, January 26 to March 23, 1878.
 - ENGINEERING, The explosiveness of coal dust: Vol. 38, 1884, p. 434. Refers to Galloway as being the first to recognize the dangers of coal-dust explosions and gives a brief summary of the experiments conducted by the Prussian Government at Neunkirchen.
 - Explosions of coal dust: Vol. 42, 1886, p. 551. Interesting historical account of early work on the problem; of value to anyone writing a general paper.
 - Coal dust an explosive agent: Vol. 58, 1894, pp. 513-516. Review of book by D. M. D. Stuart in which is described a mine explosion in the Camerton colliery. Mr. Stuart sums up the evidence pointing to the rôle of coal dust in this explosion.
 - Inflammability of mixtures of coal dust and air: Vol. 84, 1907, p. 323. A brief summary of the work of Bedson.
 - Coal-dust experiments (Pittsburgh and Rossitz): Vol. 91, 1911, pp. 826-827. Summaries of early work by U. S. Bureau of Mines at Bruceton and of experiments at the Rossitz station in Austria.

- ENGINEERING, Coal-dust explosions: Vol. 87, 1909, p. 813. An account of papers read before the Seventh International Congress of Applied Chemistry by Messrs. Bedson, Galloway, and Fastman.
- Mine gas and coal-dust ignition: Vol. 96, 1913, p. 398. General article referring to the work of Thornton, Berthelot, Mallard, Le Chatelier, Dixon, and Campbell.
- Coal-dust explosion and stone dust: Vol. 96, 1913, p. 861. Tells of experiments conducted in foreign countries and also deals with Bull. 50, Bureau of Mines.
- ENGINEERING AND MINING JOURNAL, Coal dust in colliery explosions: Vol. 32, 1881, p. 222. On early experiments, especially those by F. A. Abel, demonstrating dangers from dust in presence of small amounts of fire damp.
- Coal dust an explosive agent (review of book by D. M. D. Stuart, on conclusions from Camerton explosion in 1893): Vol. 58, 1894, p. 506; discussion of book by R. W. Raymond in Eng. and Min. Jour., vol. 58, 1894, p. 341.
- Explosive effect of electric currents on coal dust: Vol. 85, 1908, p. 722; comments, pp. 810, 1110. Discussion of ignition of coal dust by a red-hot wire.
- ENGLER, C. [Experiments]: Chem. Ztg., Jahrg. 31, 1907, p. 358; Jour. Gasbel, Jahrg. 50, p. 448; see also Chem. Ind., vol. 8, p. 171. An apparatus demonstrating the inflammability of dusts, consisting of a glass fitted with a spark gap and bellows for blowing dust through gap.
- FRAZER, J. C. W., HOFFMAN, E. J., and SCHOLL, L. A., A laboratory study of the inflammability of coal dust: Bull. 50, Bureau of Mines, 1913, 60 pp. Early work with the Frazer apparatus.
- GALLOWAY, WILLIAM, On the influence of coal dust in colliery explosions (I): Proc. Roy. Soc. London, vol. 24, 1876, pp. 239, 354-372. Describes experiments with coal dust and lamp flame; concludes that less than 1 per cent of fire damp will make fine dry dust inflammable.
- On the influence of coal dust in colliery explosions (III): Proc. Roy. Soc. London, vol. 33, 1882, pp. 490-495. Describes new dust experiments at Llwynpis colliery in September, 1880. Notes effect of moisture and shale dust in explosion at Penygraig, December 10, 1880.
- On the influence of coal dust in colliery explosions (IV): Proc. Roy. Soc. London, vol. 33, 1882, pp. 437-445. Describes 63 experiments with coal dust in July, 1880.
- On the influence of coal dust in colliery explosions (V): Proc. Roy. Soc. London, vol. 37, 1884, pp. 42-46. Reasserts belief that a mixture of coal dust and air is inflammable. Mentions explosions at Dinas colliery, South Wales, 1879.
- Experiments on explosibility of coal dusts: Proc. Roy. Soc. London, p. 168, 1886; Ann. des mines, ser. 7, t. 11, 1878, p. 229; Bull. Soc. l'ind. min., ser. 2, vol. 6, 1877; vol. 7, 1878, p. 617; vol. 9, 1880, p. 157; Bull. 20, Bureau of Mines, 1911, p. 116. Concludes coal dust could not explode under ordinary conditions of temperature and pressure, but would render inflammable an otherwise ordinarily unflammable mixture of gas and air. A wooden box 5.71 meters long and 0.305 by 0.0152 meter cross section was used as gallery.
- Coal dust: Iron and Coal Trades Rev., vol. 78, 1909, p. 885. A brief article.
- Some phases of the coal-dust question: Coll. Guard., vol. 103, January 26, 1912, p. 175; Iron and Coal Trades Rev., vol. 84, 1912, p. 128. Mainly historical; an appeal for greater mine protection through precautionary measures against ignition of coal dust.
- GARFORTH, W. E., Coal-dust explosions: Iron and Coal Trades Rev., vol. 86, 1911, p. 216. Lecture on coal-dust explosions in general.
- British coal-dust experiments: Proc. Inst. Min. Eng., vol. 42, 1910-1911, p. 220. Presidential address on the British coal-dust experiments. Brief historical review, followed by a detailed account of work at Altofts.

- GREENWELL, G. C., Reduction of pressure flowing explosion wave: *Trans. Manchester Geol. Soc.*, vol. 10, 1870, pp. 20-27. Experiments in a box 3 feet long connected with a side box showed that explosion drew air from the side box.
- HALBAUM, H. W. G., Some memoranda concerning coal dust and the essential principles of the coal-dust theory: *Trans. Inst. Min. Eng.*, vol. 39, 1909-1910, p. 728. Interesting popular article.
- HALL, H., The coal-dust question in Great Britain: *Eng. and Min. Jour.*, vol. 87, 1909, p. 1085. A review of the work of early investigators. The article also shows how legislation has reduced the number of gas and dust explosions. Very comprehensive.
- Coal dust to date: *Trans. Inst. Min., Eng.* vol. 36, 1909, p. 501; vol. 40, 1911, pp. 356-369. An interesting historical account and an excellent summary of the work on coal dust to that date. Also *Colliery Guardian*, Coal dust in mines, vol. 67, 1894, p. 319. A résumé of Hall's report to the Royal Commission. Also Experiments of Hall and Clark, communicated to the North of England Institute of Mining and Mechanical Engineers, June, 1876. Abstracted, *Bull.* 20, Bureau of Mines, 1911, p. 120. Work in an inclined gallery. Voluminous flames were obtained.
- Coal-dust and colliery explosions: *Eng. and Min. Jour.*, vol. 51, 1891, p. 738. An abstract by Hall of his paper on his experiments in shafts conducted in 1890.
- HARGER, J., The prevention of explosions in mines: *Proc. Inst. Min. Eng.*, vol. 43, p. 132. A series of tests made on dust inflammability by blowing dust through a spark gap.
- HEISE, FRITZ, and THEIM, —, Experiments on the ignition of fire damp and coal dust by means of electricity: *Trans. Fed. Inst. Min. Eng.*, vol. 17, 1899, p. 88; discussion, vol. 18, p. 183. Paper translated and abridged from articles in *Glückauf*, Jahrg. 34, 1898, pp. 1, 25, 45.
- HEWITT, H. R., Coal dust and explosives: *Coll. Guard.*, vol. 72, 1896, p. 64. Report of lectures by Hewitt at Ashby-de-la-Zouch. General review of the subject. Criticized by W. Galloway, same, p. 211; by J. Ashworth, same, p. 307.
- HILL, C., Experiments on the ignition of coal dust and fire damp: *Rev. univ. des mines*, March, 1886. Abstracted, *Eng. and Min. Jour.*, vol. 42, 1886, No. 2, p. 62. Tenuity of coal dust important, but chemical composition of coal chief factor of explosibility. Coals containing 16 to 24 per cent volatile matter are more dangerous than those poorer or richer.
- HOLTZWART, —, and MEYER, —, [Experiments]: *Dingl. poly. Jour.*, Jahrg. 280, 1891, pp. 185, 237. Abstracted, *Bull.* 20, Bureau of Mines, 1911, p. 130. Lignite dust ignited by sparks in small glass tubes through which dust was blown.
- HUTCHINSON, E. S., Notes on coal dusts and colliery explosions: *Eng. and Min. Jour.*, vol. 39, 1885, pp. 24, 35, 54; *Trans. Am. Inst. Min. Eng.*, vol. 13, 1885, p. 253. Good résumé of the work of dust factor in mine explosions up to 1885.
- IRON AND COAL TRADES REVIEW, Coal-dust explosions: Vol. 73, 1906, p. 2087. Bedson and Widdas' experiments before North of England Institute of Mining and Mechanical Engineers, December 8, 1906. Apparatus is described.
- British and French coal-dust experiments: Vol. 82, 1911, p. 159. Address of G. P. Hyslop before North Staffordshire Institute of Mining and Mechanical Engineers. Summary and comparison of Altofts and Liévin experiments.
- JONES, C. E., The explosive properties of coal dust, coal gas, and atmospheric air, with special reference to mines: *Jour. Gas Lighting*, London, vol. 13, 1883, p. 358. Concludes coal dust will not explode unless in a cloud so dense that particles touch.

- LORD, N. W., Chemical factors in mine explosions: *Mining World*, January 15, 1910.
- Chemistry and coal-mine explosions: *Fuel*, November 9, 1909, pp. 63-67.
- Abstract of paper before American Chemical Society. Discusses effect of heat of gas explosions on coal dust, benefits of moisture and of stone dust, possibility of dust explosion being a detonation.
- MALLARD, F. E., and LE CHATELIER, H., Du rôle des poussières de houille dans les accidents de mines: *Ann. des mines*, t. 160, 1882, pp. 5-96. Abstracted, *Bull. 20, Bureau of Mines*, 1911, p. 121. Mine accidents and author's experiments grouped under the following heads: 1, Mixtures of dust with air not containing fire damp; 2, mixtures of dust with air containing fire damp not sufficient for explosive mixture; 3, Mixture of dust with air containing sufficient fire damp for explosive mixture.
- MARRECO, A. Freire, and MORRISON, D. P., Ignition of dust falling on flame: *North of England Inst. Min. and Mech. Eng.*, vol. 28, 1879, p. 92. Abstracted, *Bull. 20, Bureau of Mines*, 1911, p. 116; *Ann. des mines*, ser. 7, t. 15, 1879, pp. 374-383. Record of crude experiments in which 5 liters of powder were allowed to fall on strong gas flame.
- McCUNE, R., Hastings explosion: *Coal Age*, vol. 3, 1913, p. 111. Avers that dampness halted this explosion and cites experiments at Pittsburgh in which propagation of flame by coal dust ceased when moisture content reached 30 per cent.
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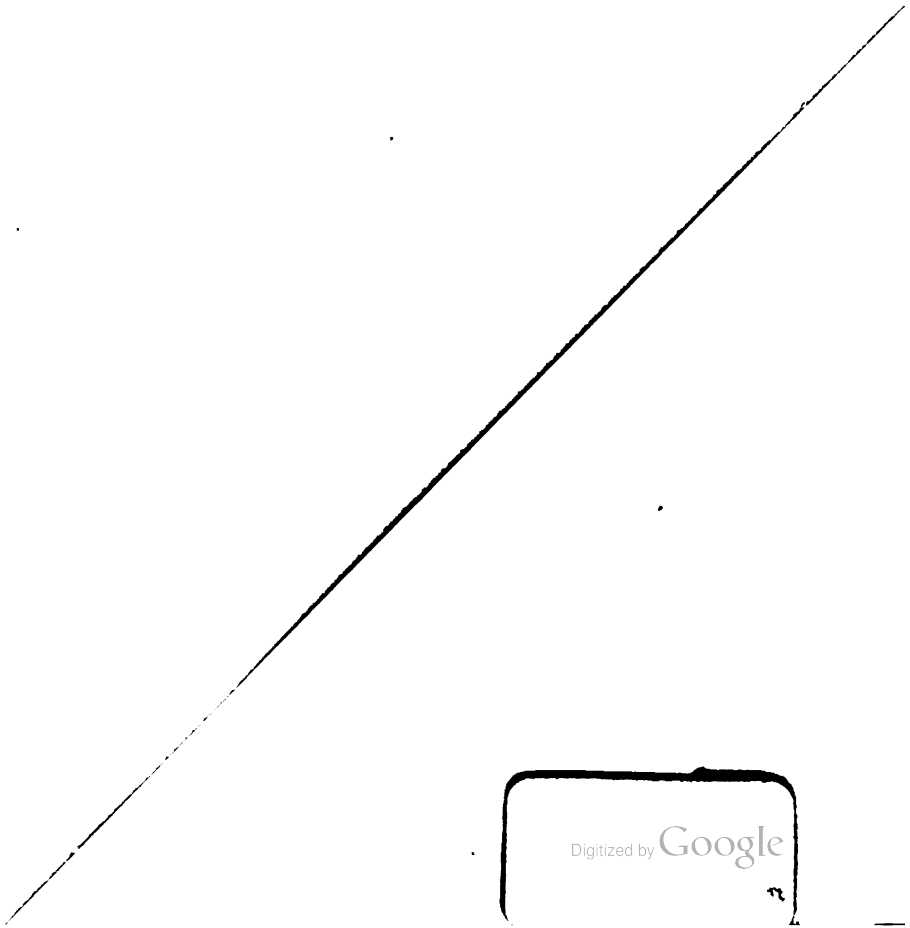
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